Knowledge Based Approach to Support Innovation Processes in Small and Medium Sized Manufacturing Enterprises

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ABSTRACT

Knowledge plays a key role in the management of innovation processes in the organisation. A large number of efforts have been made to support the innovation processes by academics and practitioners in the field of Innovation and Knowledge Management. As a result, there are several methods and approaches now available for companies to manage their innovation knowledge more effectively. However, the aspects of knowledge identification, storage and utilisation to support innovation processes has not been researched extensively. In addition, it is argued that the existing methods and approaches which were originally developed and implemented in large organisations do not meet the special requirements of Small and Medium Sized Enterprises (SMEs). Therefore, there is a need for more research to investigate what information and knowledge sources are being used, how these sources are stored and when they are utilised in the innovation process in SMEs.

This thesis inspects the above mentioned issues in greater depth by conducting a series of case studies of the innovation processes in SMEs. The research has been specifically focused on the needs of SMEs in the manufacturing sector and has studied product, process and service innovation. This research programme commenced with a thorough study of the current literature associated with Innovation, Innovation Models, Knowledge Management, Quality Circle Programme and Learning Organisation. The second stage of this research has utilised the findings from the literature review to develop a novel research framework to examine current innovation and knowledge management practices in use within manufacturing SMEs. The programme applied primary research methods to validate the knowledge gained from the secondary research. The UK based manufacturing SMEs were used as test beds to investigate and understand their innovation practices, tools and procedures applied in their innovation processes; and to gather responses to key research questions. In the third stage, the results from the previous stages were utilised to develop a novel knowledge-based innovation framework that implements a new methodology for the adoption of innovation processes in manufacturing SMEs. The construction of the novel innovation framework has been based on individual practices found in traditional problem-solving approaches such as the Quality Circle Programme, combined with a selected group of practices obtained from different management processes such as Knowledge Management and team learning and sharing practices such as Learning Organisation. The fourth stage implemented the proposed framework as a software tool that can be used to support innovation processes. In the final stage, the thesis was concluded with the validation of the proposed knowledge toolset, discussion on the validation results and the application of the toolset to support innovation processes in manufacturing SMEs.

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ABBREVIATIONS

CAD	Computer-aided Design
CAM	Computer-aided Manufacturing
CBR	Case Based Reasoning
CIP	Collaborative Innovation Platform
CKR	Central Knowledge Repository
EC	European Commission
EU	European Union
FOAF	Friend of a Friend
ICT	Information and Communications Technology
IM	Innovation Management
IQC	Innovation Quality Circle
KBS	Knowledge-Based Systems
KM	Knowledge Management
LO	Learning Organisation
NPD	New Product Development
NPDTs	New Product Development Tools
QCP	Quality Circle Programme
R&D	Research and Development
RTD	Research and Technological Development
SMEs	Small and Medium sized Enterprises
TQM	Total Quality Management

LIST OF RELATED RESEARCH PUBLICATIONS

Singh, L. (2018) Knowledge based approach to support innovation processes in SMEs, *De Montfort University Research Showcase*, Leicester, April, 2018.

Singh, L., Ziarati, R., Ziarati, M., Gatward, R. and Chen, F. (2016) Investigation into the Design and Development of Knowledge-Based Innovation Processes in Manufacturing Companies. In *Advances in Manufacturing Technology XXX: Proceedings of the 14th International Conference on Manufacturing Research, Incorporating the 31st National Conference on Manufacturing Research, September 6–8, 2016, Loughborough University, UK* (Vol. 3, p. 413). IOS Press.

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CHAPTER 1 - INTRODUCTION

1.1 Research Background

Due to globalisation, businesses and retail customers are enjoying an ever-increasing range of products offered at competitive prices and in return manufacturing businesses are facing constant competition to remain in business. On top of the recent economic crisis, the low-cost competition from the East has augmented the European manufacturing industry’s problems. This has amplified the need for manufacturing businesses to be flexible and consider new, effective and efficient ways of working as well as seeking new tools and technologies that will allow them to remain competitive and able to respond rapidly and cost-effectively to their customers' demands.

Regarding cost of producing goods and services, excluding most of high value manufacturing, it is nearly impossible for European manufacturing companies to beat Eastern companies. This is mainly because the latter has a much lower labour cost than the former. The way European manufacturing companies have managed to compete is through innovation (BIS Economics Paper No. 10A (2010)).

The UK manufacturing industry has a strong history of innovation as well as wealth of skills and know-how. By harnessing employees' technical abilities as well as motivating learning and developing strong research and development capabilities, the UK manufacturing industry has applied innovation in several sectors such as aerospace, defence, nanotechnology to stay in competition (BIS Economics Paper No. 10A (2010)). Such innovations should continue and be transferred to other manufacturing sectors such as automotive, maritime and so forth. The introduction of innovation should not only be in technological areas but also applied in every area of the manufacturing organisation, starting from employees' daily work activities to the production and service provision areas.

There are several factors that influence organisations' capacity to innovate. Academic literature widely acknowledges that Learning Organisation (LO) plays a key role in boosting firms' performance and ability to innovate (Wang and Xu, 2018; Sony and Naik, 2012; Wang et al., 2010; Baker and Sinkula, 1999; Alegre and Chiva, 2008; Calantone et al., 2002). In particular, some papers (Wang and Ellinger, 2011; Baker and Sinkula, 1999; Hurley and Hult, 1998; and Han et al., 1998) reported that the companies who facilitate the learning of their employees, develop the capabilities that enhance innovation capacity and improve overall performance. In addition, there are several publications describing theoretical models developed by academics and practitioners in this field [Innovation Management] which highlighted a positive correlation between Learning Organisation and Innovation (Stata, 1989; Nonaka, 1991; Coombs and Hull, 1998; Hage, 1999; Leonard-Barton, 1995; Nooteboom, 1999; Sorensen and Stuart, 2000; Hall and Andriani, 2003). Therefore, it is important for individuals to keep acquiring new knowledge and share it with the organisation to foster innovation. The capacity to acquire new knowledge depends upon the organisation's knowledge base (Salavou and Lioukas, 2003) and its ability to acquire information and knowledge from external sources (Chang and Cho, 2008). Whereas, the firm's ability to acquire external knowledge depends on its ability to understand, assimilate and take it [knowledge] to the commercial level (Cohen and Levinthal, 1990). Nonaka (1994) also expressed similar views and stated that the act of sharing information and knowledge that generate new and common insights creates innovation. In short, knowledge acquisition, storage, assimilation, and learning practices can help firms' to boost their innovation capacity and to gain competitive advantage.

While making efforts on encouraging knowledge sharing, learning and imposing innovation in products and services, it is mandatory to meet the quality expectations of the customers. By ensuring consistent and repeatable quality, manufacturing companies can strengthen their brand image and can build trust. Manufacturing companies can introduce organisation-wide Quality Circle Programme (QCP) to achieve consistent quality. QCP is a well renowned management technique to gain competitive advantage through Total Quality Management (TQM).

It has also been noted that the Innovation process differs with respect to the firms' characteristics such as size, industry, revenue, etc. Therefore, there is a significant difference in innovation processes at larger companies than in the smaller firms (Cogan, 1992, cited by Kleinknecht, 1993). To adapt innovation processes for Small and Medium Sized Enterprises (SMEs), it is important to address their special characteristics such as less formality, often non-existence of an innovation driver/manager, smaller R&D projects, less defined company strategy, small development groups (Madrid-Guijarro et al., 2009; Huang et al., 2002). One of the main characteristics of these organisations is lack of adequate resources for innovation processes and research activities which is often used as an excuse for the absence of systematic innovation. The existing innovation frameworks which were primarily designed for the big organisations have failed to address the aforementioned characteristics of the manufacturing SMEs. Literature has highlighted several obstacles for Innovation Management (IM) in smaller firms (Peck et al., 2018; Mendy and Hack-Polay, 2018; Braidford et al., 2017; Demirbas et al. 2011; Madrid-Guijarro et al., 2009; Scozzi et al. 2005; Mcadam et al., 2004). Therefore, there is a significant need to re-visit innovation management principles for the design and development of an innovation framework especially tailored to respond to the needs and characteristics of small and medium sized manufacturing enterprises. Kelly and Kranzburg (1978) defined the term Innovation

Management as a process of managing product and organisation innovation with set of tools which allow employees and other member of extended organisation to cooperate with a view to achieve the common goals and objectives.

1.2 Industrial Sponsor

This research study is sponsored by Centre for Factories of the Future (C4FF) Ltd. C4FF is a SME with RTD (Research, Technical and Development) capacity based in Kenilworth, UK. C4FF is the instigator of the Factories of the Future projects in the UK and supported similar developments in the EU.

C4FF has an established reputation for developing novel manufacturing systems and software for factory management, including for lean practices. They also have many years of experience in Information and Communications Technology (ICT) and Manufacturing research and development, as well as instrumentation and control projects. They have developed several CNC (Computer Numerical Control) systems in collaborations with machine tool manufacturers, and their work led to a new Clean Diesel Engine System and the Management System that accompanies it. C4FF has extensive experience of developing complex software systems, validation and testing both in the scope of European research projects and industrial projects.

Since the Company was founded in 1996, C4FF has gained extensive experience in participating and co-ordinating EU and UK funded RTD projects in areas such as: Artificial Intelligence Systems, Sales Forecasting, Market Intelligence Knowledge Extraction, Innovation Management, Factory automation and Enterprise Resource Planning. As a result, the Company has developed several novel business intelligence tools that could be used to manage and improve business processes. One of the tools is called

ComeUpWithAGreatIdea.com, which is primarily designed to support manufacturing SMEs in their innovation activities.

1.3 The Research Rationale

This research is a part of C4FF's initiative to design and develop a dedicated innovation platform for manufacturing SMEs, which was co-funded by European Commission under Framework 7 research project called ExtremeFactories (Project id: FP7-ICT-2011-285164). The ExtremeFactories consortium was formed by 11 organisations from 4 European countries (Spain, Germany, United Kingdom and Finland), including 7 industrial manufacturing SMEs and 4 RTD centres.

While working with SMEs, especially in the ExtremeFactories project, the Company often found shortages of appropriate organisational knowledge management strategies, as well as absences of methods and tools for manging the information and knowledge required in their innovation activities. This resulted in smaller companies having limited capacity to innovate and not able to achieve the desired level of productivity.

To this end, this research programme was commissioned to supplement C4FF's ongoing initiatives to support manufacturing SMEs by investigating the design and development of a novel framework composed with a knowledge repository that could be used to make innovation processes more effective. The idea was to link the knowledge repository with the innovation framework and provide options to the innovator, decision makers, young staff members to look at related information or similar cases before presenting his/her idea or making decision on specific idea.

1.4 Research Aims

The intention of the research project is to make contribution to the research and knowledge surrounding the use of knowledge storage and utilisation in Innovation processes in manufacturing SMEs. Therefore, the main aim of the research is:

To create and evaluate an innovation framework incorporating novel knowledge repository to support innovation processes in manufacturing SMEs.

The knowledge repository is intended to be used in the innovation processes to provide greater access to organisational knowledge for employees and other actors involved in the innovation process. It is believed that the knowledge repository will help manufacturing SMEs and their employees to learn from the company's past and current knowledge before suggesting new ideas for improvements or transformations (i.e. new product, service, practice, process etc.)

1.5 Research Objectives

The objectives of research project are clarified using high level and low level research objectives.

The high level objectives of the research are aimed to:

- Investigate the design and development of a novel Central Knowledge Repository (CKR) for the products and processes of manufacturing SMEs and associated New Product Development Tools (NPDTs) to enable rapid and cost effective new products, services and processes introduction.

- Develop an innovation framework for enabling manufacturing-based SMEs to use the CKR & NPDTs to improve new product development competences that allow manufacturing operations to become flexible and more efficient.

The above objectives will incorporate the necessary tools to support the whole life-cycle of the innovation process (from the conception of an idea to its implementation). In order to achieve the high level objectives, a number of low level objectives were formulated. These low level objectives provide more specific individual components of the research project; focusing on the details of rudimentary micro stages of the project. The low level objectives are composed of six objectives:

Objective 1: Investigate what SMEs understand by "innovation" and the general views associated with it by focusing on SMEs within the manufacturing sector.

The first objective reviews the general definition of innovation and its models. It also covers general views about innovation and innovation processes in manufacturing SMEs to define the scope and area of the research problem. To achieve this objective, the following three activities are planned:

- Carry out a critical literature review to examine and evaluate the definition of innovation and models proposed by researchers and practitioners in this field. This activity will identify the meaning of innovation from the SMEs' perspective and discover processes that are thought to support innovation in manufacturing SMEs.

- Conduct a literature review of related management approaches that are believed to enhance the innovation capacity of the organisation; and evaluate their viability to support innovation processes in manufacturing SMEs.

- Conduct a preliminary survey to determine current processes, procedures to encourage innovation; and practices for storing documents used in the innovation processes in manufacturing SMEs.

Objective 2: Investigate challenges, unique requirements, characteristics and current innovation practices across manufacturing SMEs.

The second objective aims to pinpoint the challenges faced by manufacturing SMEs in the innovation processes, identify their unique requirements as well as the characteristics that need to be addressed by the intended Innovation framework. To achieve this objective, the following four activities are planned:

- Conduct a review of the academic and practitioner's literature to identify challenges, unique requirements and characteristics of manufacturing SMEs. This will form a list of requirements with a view of using them to develop a specially tailored innovation framework for manufacturing SMEs.

- Conduct detailed case studies to identify strengths, weaknesses and gaps in the existing innovation practices applied in manufacturing SMEs.

- Compare the innovation practices of participating manufacturing SMEs with the literature concerning innovation in SMEs and clarify how it differs from the practices applied by large organisations.

- Produce an innovation process map that reflects how the innovation processes work within manufacturing SMEs based upon identified actors, inputs, outputs and activities of the innovation processes.

Objective 3: Examine and evaluate the current knowledge storage and utilisation practices and tools utilised in the innovation processes in manufacturing SMEs.

The third objective covers the investigation of knowledge storage and utilisation practices applied by manufacturing SMEs with a view to identify strengths, weaknesses and gaps in existing practices. To achieve this objective, the following three activities are planned:

- Conduct a literature review to examine the knowledge storage and utilisation practices in use within manufacturing SMEs.
- Further examination of identified innovation processes, from Objective 1, to identify and evaluate the knowledge storage and utilisation practices of manufacturing SMEs.
- Interview the actors involved in the innovation process to identify the existing tools, information and knowledge sources that are being used in the innovation process; and find out potential tools and knowledge sources that could also support the innovation process.

Objective 4: Produce a Knowledge Based Innovation framework that could be applied to drive innovation in manufacturing SMEs and evaluate its impact to support innovation processes.

The fourth objective covers the design and development of a knowledge-based innovation framework with inputs from the previous objectives. The following activities are planned to achieve this objective:

- Extend the ExtremeFactories Innovation methodology by integrating knowledge management process with an aim to develop a novel combinatorial framework that will offer a knowledge-based approach to manage innovation processes in manufacturing SMEs.

- Modelling the innovation process of the selected manufacturing SME to produce a model for the Knowledge Storage and Utilisation service; and identify the database schema and information sources that are being used in the innovation process.

- Design a CKR based on the identified database schema from activity 2 of this objective; and the information and knowledge sources discovered in Objective 3.

Objective 5: Design and development of the proof of concept to demonstrate how the proposed framework can be applied in a real industrial environment.

The fifth objective intends to design and develop the system prototype to demonstrate how the proposed knowledge-based innovation framework will work in practice. This objective is broken down into three activities:

- Examine potential software development tools for the implementation of the Knowledge Storage and Utilisation services, which could be used to support innovation in the manufacturing SMEs.

- Implementation of the system prototype for the Knowledge Storage and Utilisation services that could be used to support learning and drive innovation within manufacturing SMEs.

- Develop a Knowledge Repository based on the identified schema in Objective 4 and populate it with the information and knowledge sources previously identified in Objective 4.

Objective 6: Validate the system prototype by publishing the results within the participating SMEs.

The last objective covers the validation of the developed toolset, and discusses the results of the system piloting in the participating organisations. To achieve this objective, the following three activities are planned:

- Carry out a laboratory-based system testing for the initial validation of the proposed proof of concept using data collected from the participating organisations.
- Conduct a series of interviews with employees of participating SMEs to seek their views on the system's practicability to support the innovation processes.
- Publish research results in academic conferences/events to get feedback and promote discussions.

1.6 Research Contribution to Existing Knowledge

This research programme is making the following contributions to the existing knowledge:

1. **Expanding the existing model** - This research is primarily an expansion of Innovation methodology developed as a part of ExtremeFactories project. It is integrating information and knowledge about design, marketing, management, manufacturing procedures and practices in the form of novel repository. This repository will promote learning in the organisation to help SMEs to generate new ideas using a combination of simultaneous idea generation and evaluation prior to formal idea submission by using internal and external sources available in the knowledge repository. Thus, the company will not only trigger innovation processes motivated by external factors, but it will

naturally be able to originate new innovative product and process ideas within the organisation with reference to previous product or process developments.

2. **Combining the existing methodologies and proving that the combination reveals something novel and beneficial** – The research combines existing methodologies i.e. Innovation Management, Learning Organisation and Knowledge management practices and shows how the arrangement can help make innovation processes more effective. A combinatorial approach to innovation is a new addition to existing methods in Innovation Management literature on SMEs.

3. **Implementing and demonstrating a theoretical concept – presenting how it can be applied in a real industrial environment** – A literature review has shown that Learning Organisation and Knowledge Management approaches have a positive impact on the organisations' innovation outcomes. This research programme demonstrated an innovation framework in the form of a real tool powered with a central repository consisted of a number sub-repositories thus making ideas tangible; and demonstrated how these theoretical approaches work in practice. The outcomes of these validation activities contribute to new knowledge substantiating the learning and sharing of knowledge intended to increase innovation effectiveness.

4. **Proposing new method to solve a known problem and signifying the method's efficacy** The proposed knowledge based innovation framework suggested a new way to help companies to seek improvements (daily, tactical or strategic) on a continuous basis and by having access to useful knowledge. This is to help them to make the right decisions and hence prohibiting the generation of waste in the first place. This new approach is an addition to the existing methods.

1.7 Structure of the Thesis

The thesis structure has been composed of following chapters:

Chapter 1 - Research Overview

Chapter 1 provides an introduction to the research programme, the rationale behind the research, and clarifies its aims and objectives.

Chapter 2 - Literature Review

Chapter 2 provides in-depth analysis of past and current research related to the area of research. The chapter starts with brief history of the manufacturing industry and discusses problems and issues faced by companies in this sector. The chapter then provides insights into how Innovation is defined and evaluates existing innovation models. The other subjects covered in this chapter include Knowledge Management, Learning Organisation, and Quality Circle Programme.

Chapter 3 – Research Methods and Methodology

Chapter 3 provides an overview of research methods and methodology. It covers details of the research approach that was applied to achieve the aims and objectives defined in Chapter 1.

Chapter 4 – Knowledge Management and Innovation Practices in Manufacturing SMEs

Chapter 4 examines the current knowledge management and innovation practices followed by the manufacturing SMEs to identify requirements, information and knowledge sources and existing tools. The results of preliminary survey and case studies are also discussed in this chapter.

Chapter 5 – Proposed Knowledge based Innovation Framework

Chapter 5 discusses the results of the research and proposes a novel knowledge-based innovation framework to support innovation processes in the manufacturing SMEs. The proposed framework is a new addition to the existing methods to support innovation processes in manufacturing SMEs.

Chapter 6 – Development of Knowledge Model using CommonKADS Methodology

Chapter 6 describes in detail the implementation of CommonKADS methodology in selected knowledge intensive innovation processes in participating manufacturing SMEs, to identify the knowledge requirements; and discover information and knowledge sources to support the development of knowledge toolset.

Chapter 7 - Knowledge based Innovation Approach and its Toolset Implementation

Chapter 7 covers details related to the design and development of the Knowledge based Innovation toolset and its applications to support innovation processes in manufacturing SMEs.

Chapter 8 - Validation of the Proposed Research

Chapter 8 discusses the evaluation of the proposed knowledge toolset for knowledge storage and utilisation using datasets from the selected business case and its potential to support innovation in manufacturing SMEs.

Chapter 9 - Conclusion and Future Work

Chapter 9 concludes with the key findings of the research, contributions to the existing knowledge, research implications and areas for further research.

1.8 Summary

To summarise, this chapter provided details on the research rational and its aim and objectives. It also covered the structure of the thesis. The next chapter discusses the literature in the area of Innovation Management, Knowledge Management, Learning Organisation and Quality Circle Programme.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of the literature in the area of Innovation Management, Learning Organisation, Quality Circle Programme and Knowledge Management. It starts with a brief history of the manufacturing revolution and then provides insight into the problems of modern manufacturing organisations and their struggle to cope with the current fast-paced and highly competitive economic playground. In order to address manufacturing problems, this chapter exemplifies the concept of Innovation Management, where five models of IM have been discussed in context of current research. Also, a brief introduction about Knowledge management and knowledge repository is presented which further leads to detailed description on different methods and techniques for the design and development of the proposed knowledge repository. Furthermore, the chapter moves to outline the philosophy of LO and QCP, where characteristics and best practices of both techniques are taken into consideration for the design of combinatorial innovation framework.

2.2 Brief History of Manufacturing Industry

Manufacturing has a fine history of adapting itself as per customer demands and economic environments. Between the 18th and 19th century the manufacturing industry witnessed a remarkable transformation in manufacturing history. This was the time when machines were introduced first-time to carry out production work. This era in history is known as the Industrial Revolution. A transition was made from man-made products to machine-made products. As machines were able to work faster than men, they reduced the production cost and shortened the manufacturing lead time. Thus, the companies were able to sell the same goods at lower prices, which often led to higher sales and profit margins.

The lower product price enabled customers to buy more goods which results in greater demand than supply. The manufacturing industry responded to this higher demand with the introduction of the “mass production” concept, which was the result of Henry Ford's idea of moving assembly line that revolutionised the manufacturing processes of his Ford Model T (Kang, 2012).

With the advent of materials being produced at higher pace and in larger quantities, the need for maintaining quality became a major challenge. Pioneered by Japanese automotive group Toyota, a methodology for maintaining and improving the integrity of production, new quality systems came into existence, which is known as Toyota Production System (Kang, 2012). In parallel, another methodology called Total Quality Management (TQM) became also very popular in manufacturing businesses for managing and controlling quality. It involves everyone in the organisation and encompasses all its functions to establish permanent climate in which firm can continuously enhance its capability to deliver high-quality products and services to its customers.

The world economy has changed drastically in the last decade. The recent economic crisis has affected the buying power of customers and businesses whilst globalisation has increased customers' expectations for higher variability in products/services. This behaviour forces manufacturing companies to continue to “reinvent” themselves as well as their products and services to retain or increase their share of the market. Applying quality control and management practices are not enough to gain competitive advantage any more. It is important for the manufacturing industry to focus on eliminating waste in production to keep manufacturing cost down and apply innovation in manufacturing processes to design and develop innovative products as well as services to fight against ever increasing low-cost economies.

The Lean Manufacturing approach, coined by John Krafcik (Kumar et al., 2014), is supporting manufacturing in eliminating waste in a systematic way. By applying innovation practices manufacturing companies can effectively respond to the challenges of uncertain customer demands with innovative products. Thus, innovation and creative approaches to manufacturing is the only way forward for manufacturing organisations to make their products and services stand out in the market. Many larger organisations have already realised the importance of innovation and implemented it in their manufacturing processes as well as their products and services. Some of the most innovative companies who have achieved competitive advantage through innovation are Apple, P&G, and Airbus.

2.2.1 Manufacturing Problems

The traditional manufacturing systems suffer from variability in the manufacturing environment; the increase in variability minimises the efficiency of manufacturing system (Kang, 2012). Kang (2012) argued that the reason for manufacturing deficiency for handling variability was old design of manufacturing systems which were only designed to work with low variability conditions. Hence, the old manufacturing systems have failed to cope with the current requirements of producing high variety and low volume productions. The Table 2.1 provides a glance of the key traditional manufacturing system conditions.

Table 2.1 - Traditional Manufacturing System Conditions

– Stable customer demand – High volume and low product variability – Limited variation in product design i.e. similar design with limited product range – Limited processing and tools – Shorter or less changeovers due to low product variety – Limited product routings – Continuous production

(Source: Yusuf and Adeleye (2002); and Khalil et al. (2008) as cited by Kang (2012)

On the contrary to traditional market, current environment is rather competitive, and customers demand higher variability in products/services which require greater amount of innovation in design and manufacturing. In addition, low cost competition from the East is making situation worst for European manufacturing companies particularly SMEs. Globalization and tough competition has left no option for small business owners other than to continue to reinvent themselves as well as their products/services to survive and compete in this fast-changing economic environment. Earlier quality in manufacturing products and services was enough for getting competitive advantage, now innovation is the way forward for survival, growth and development of the small and medium-sized enterprises (Acs and Audretsch, 1990 as cited by Lemonakis et al., 2013)..

2.3 Innovation

Innovation is an important aspect of manufacturing businesses, as it encompasses the development of innovative products and new and creative approaches to production processes and management. In short, it plays a central role in all levels of manufacturing.

2.3.1 Definition of Innovation

The term innovation can be defined as a journey of taking an idea from concept to reality. Trott (1998) shows similar views and defines it as a process of converting an idea into a commercial and practical application. A simple definition of innovation can be defined as the ability of a company to create something new in a burst of creativity to bring about improvements in a way of doing things which benefits both company and its customers. Ziarati defines innovation as 'Business not as usual' (Ziarati, 1995).

Over the past few decades, the word "Innovation" has become one of the hottest topics in the business world. A large amount of research has been carried out in this field. Measuring the extent of work published around innovation management, Mangematin and Baden-Fuller (2008) reported that the majority of research papers and articles (approximately 5000 papers each year) produced by research centres (around 200 in all over the world) are focused on innovation management. In his book, Baumol (2002, pp.13), states *"virtually all of the economic growth that has occurred since the eighteenth century is ultimately attributable to innovation"*. Innovation does not only support individual company growth but also results in overall economic growth of the country (Romer, 1987). A survey done by Businessweek in 2006 as cited by Hauptly (2008) has revealed that during the period of 1995-2005, the median profit margin of top innovative companies was 3.4% and median annual stock return was 14.3% whereas for the rest of the firms was 0.4% and 11.3% respectively. Therefore, it is evident that innovation is the way forward for manufacturing SMEs to survive in the current competitive environment.

Literature on innovation has created a plethora of definitions. Urabe et al.(1988) (cited in Urabe, 1988, pp. 3) define innovation as the generation of new ideas which lead to introduction of new products, processes or services resulting in overall economic growth.

Rubenstein (1989) also presented similar view and defines innovation as *"the process whereby new and improved products, processes, materials and services are developed and transferred to a plant and/or market where they are appropriate".* Similarly, Fagerberg (2009) describes innovation as the commercial exploitation of a new idea or invention whereby commercial exploitation is the act of taking the product or process to the market and selling it to people. Innovation is typically associated with a research and development (R&D) department. However, a heavy budget for research and development is not a prerequisite to bring about innovation and improvement in a company. Sometimes a suggestion from employees can bring about an innovative idea that eventually develops into a successful product (for example, Post it notes that was just a suggestion from an employee of 3M).

Researchers have defined Innovation differently over a period of time. Other examples of innovation definitions are presented below.

> *"An innovation really means something 1) new with high-level of originality, 2) in whatever area 3) that also breaks in to (or obtains a foothold in) society, often via the market, and 4) mean something revolutionary for people." (Frankelius, 2009, pp. 49)*

> *"Innovation refers to the process of bringing any new, problem-solving idea into use. Ideas for reorganising, cuttings costs, putting in new budgeting systems, improving communication, or assembling product in team are also innovation. Innovation is the generation, acceptance, and implementation of new ideas, processes, product, or services." (Kanter, 1983, pp. 20)*

To conclude, it can be stated that the innovation includes everything - products, services and processes, and covers major transformation (radical innovation) as well as small improvements in product/process/services (incremental innovation) and occur at all level of the organisation.

2.3.2 Existing Methods and Tools for Innovation

There is no dispute over the significant contribution made by SMEs' to the economic growth of Europe (EC, 2012). Whilst some research (Heikkilä et al., 2018; Kumar et al., 2017; Ates et al., 2013; Ziarati et al., 2002; Ziarati and Khataee, 1994) has already begun to make SMEs more innovative, the existing initiatives such as UNE 166000 series for Innovation Management (AENOR) and the activities performed by the European Committee for Standardisation are found to be time consuming and expensive to initiate and manage innovation especially in firms with no prior experience (Mir and Casadesús, 2011; Pellicer et al., 2006). These efforts are also criticised for not being in line with the requirements of many manufacturing SMEs; requirements such as the capacity to be agile, flexible and cost-efficient (Ziarati et al., 2013). In general terms, manufacturing SMEs cannot afford to implement methods or tools to adopt or adapt innovation as a part of their business processes, although innovation is important for businesses to remain solvent and compete in the current hyper-competitive economic environment.

An effective strategy/system is urgently required to support manufacturing SMEs to fight against such problems. One of the immediate initiatives could be the introduction of an innovation framework which would enable them to come up with creative ideas to produce innovative and high-quality products/services by engaging all the members of organisation (Li and Xu, 2008; ZhongCheng and Pengzhu, 2005).

A virtual online collaboration system is regarded as a possible way to engage all the members of the organisation to manage innovation processes. Chen et al. (2011) proposed a virtual design platform to bring innovation in the design and development of new product(s) by engaging customers into the design processes. The framework is based on a theoretical model. It takes input from customers and connects customers' information and product orientation for product innovation. However, there is no mention of the other actors of organisation such as the company's employees, suppliers, stake holders, partners and so forth, which are integral parts of an organisation. This platform supports products/services innovation; there is no mention of process innovation.

Most of the existing idea generation and management systems suffer from a large number of ideas being generated and the challenges of selecting the best from them (Henning, 2010). In the recent years, a number of applications have been developed which allow companies to capture, manage and prioritise ideas e.g. MileMaker[1], My Starbucks Idea[2] and Idea Sandbox[3] etc. 'My Starbucks Idea' is one of the most popular web applications that allow users to enter new ideas and vote on their favourite ideas using "Thumbs up and down" approach. In a recent study by Henning (2010), over 94,000 ideas have been submitted to "My Starbucks Idea" platform. Now the first question that strikes our mind is how one can decide which idea will be the next blockbuster. Henning (2010) argues that the prioritization tools used by "My Starbucks Idea" are not good enough to prioritise a big list of ideas to suggest the most promising ones. Even the approach of moving "idea up and down" has its own drawbacks. Generally, idea management websites have one or two views to display ideas and what usually happens is people rate the most popular ones and disregard the unpopular ideas. Therefore, there is always a risk for a new idea to be getting overlooked because of the popularity of the less feasible ideas in the list.

Existing methods and tools to support innovation are directed mostly at solving scientific problems, and not those of industrial manufacturing. Available methods for innovation

[1] http://getmilemarker.com/index.html accessed on 01/06/2012
[2] http://mystarbucksidea.force.com/ accessed on 29/07/2013
[3] http://www.idea-sandbox.com/ accessed on 01/08/2013

knowledge management are too elaborate for industrial SMEs and do not involve all relevant actors, nor do they properly support systemic innovation.

In light of above mentioned issues and to address the gap in literature, there is a need of a framework specifically designed for SMEs with view to address the problems of identifying ideas and how they should be prioritised and selected in more effective and efficient way. It is also important to create an environment of good ideas to be generated such as developing a learning organisation within the enterprise. Irrespective of the effectiveness and efficiency of generating and prioritising ideas, there is also a need for a dedicated repository to store information about SMEs' goals, practices and so forth in an electronic format.

2.3.3 Evolution of Innovation Models

A study on the innovation models, by Rothwell (1994) presents five generations of an innovation process model. The study clearly shows that the growing complexity and pace of the industrial technological changes and uncertainty in market demand have changed the innovation processes from a closed innovation process to more collaborative approaches. A summary of all five generations of the innovation process models is presented in the following sub-sections.

2.3.3.1 1st Generation - Technology Push Models (1950s — Mid-1960s)

The first generation of innovation process model demonstrates that *"technological developments within innovative organisations' are the main source of innovation"* (Conway and Steward, 2009). This argues that companies were achieving innovation by investing in technology focusing on the 'supply-side' in contrast with the later model which draws attention to the importance of customer demand. As shown in Figure 2.1, the innovation is solely depends on the scientists to discover something new which are then designed, developed and tested internally before commencing mass production and commercialisation. Such linear process to innovation may work well for industries, like pharmaceutical, but it might not suit the needs of manufacturing who work under extreme pressure to develop things quicker and in innovative way. Trott (2002) also expressed his concerns and stated that this model is difficult to generalise to all the industries due to their cultural and financial differences and most importantly the way in which innovations are created.

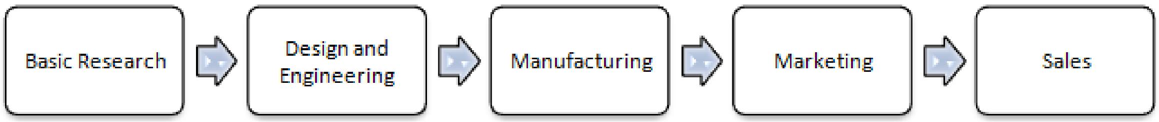

Figure 2.1 - Technology Push Model

2.3.3.2 2nd Generation - Market Pull Models (1960s - 1970s)

The development of Market Pull Innovation Model was a result of the research work undertaken in the 1960s and 1970s that emphasise the importance of market need on innovation process model (Hippel, 2001). This led to a diversion of focus from technology investment to market research to understand the market needs. From the market research findings, new products and services can be manufactured to meet the market needs and requirements; and give businesses competitive advantage. It also requires action from management to focus business strategies to satisfy these market needs. As shown in Figure 2.2, the model put greater emphasize on addressing customers' needs to become innovative and gain competitive advantage over rival businesses. The model suggests using customer feedback as a medium to generate ideas for new product and/or services development and also to make incremental changes to the existing product and/or services. The diagram below is adapted from Trott (2002) and demonstrates Market Pull innovation model.

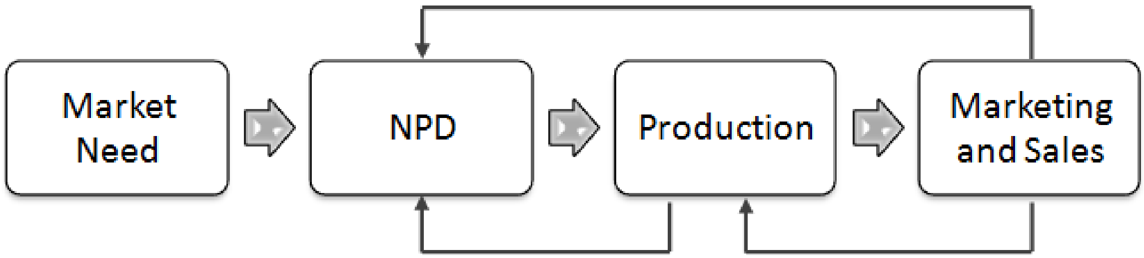

Figure 2.2 - Market Pull Model

Similar to Technology Push mode, this model cannot be generalised for all industries due to the nature of the work and environment in which they operate. Moreover, these models [Technology Push Model and Market Pull Model] are out of date (Galbraith, 1982 cited in Trott, 2002) and don't provide complete picture of the innovation process. They only indicate what drives innovation in the organisations and don't illustrate how it occurs.

2.3.3.3 3rd Generation - Coupling and Interactive Models (1970s - mid-1980)

In order to address the issues in previous models, the new models came into existence. These are classified as third generation innovation models. As stated earlier, the first and second generation models only give an idea about what is triggering the innovation i.e. customer needs or technology and missing the point how innovation occur. The desire of exploring what triggers innovation gave birth to a new innovation model, known as Simultaneous Coupling Model, shown in Figure 2.3. This model proposes that innovation is fostered as a result of simultaneous coupling of knowledge between manufacturing, marketing and research and development (Trott, 2002). Hence, the knowledge is a key pillar for this model to work. Unlike previous models, there is no explicit starting point for innovation. Researchers also described this model as *"a confluence of technological capabilities and market needs within the framework of the innovating firm"* (Rothwell and Zegveld 1985, cited in Conway and Steward, 2009, pp. 68). The model integrates the marketing with research and development together. The managers are required to setup formal or informal interactions and relationship between different departments. The following diagram of Coupling and Interactive models is adapted from Trott (2002, pp. 18).

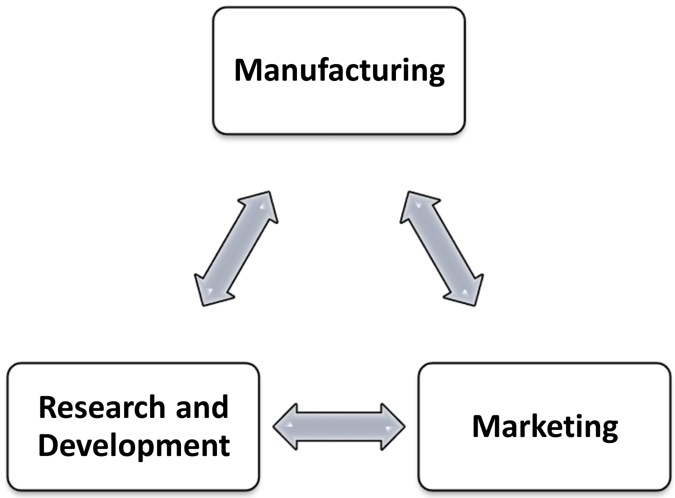

Figure 2.3 - Simultaneous Coupling Models

The interactive models integrates both linear models, i.e. technology push and market pull models, together and emphasises that *"innovation occur as the results of the interaction of the marketplace, the science base and organisation's capability"* (Trott, 2002, pp. 19). Similar to coupling model, the model do not have any specific starting point for innovation. Although, this model looks like linear models information flow is not restricted and allows it to rise from a variety of areas.

The overall innovation process is very complex as outlined in Figure 2.4; representing internal and external linkages and connections between the organisation's capability both on the marketplace and the science base. Hence, it is important for an organisation to effectively manage these relationships in order to be successful at innovation.

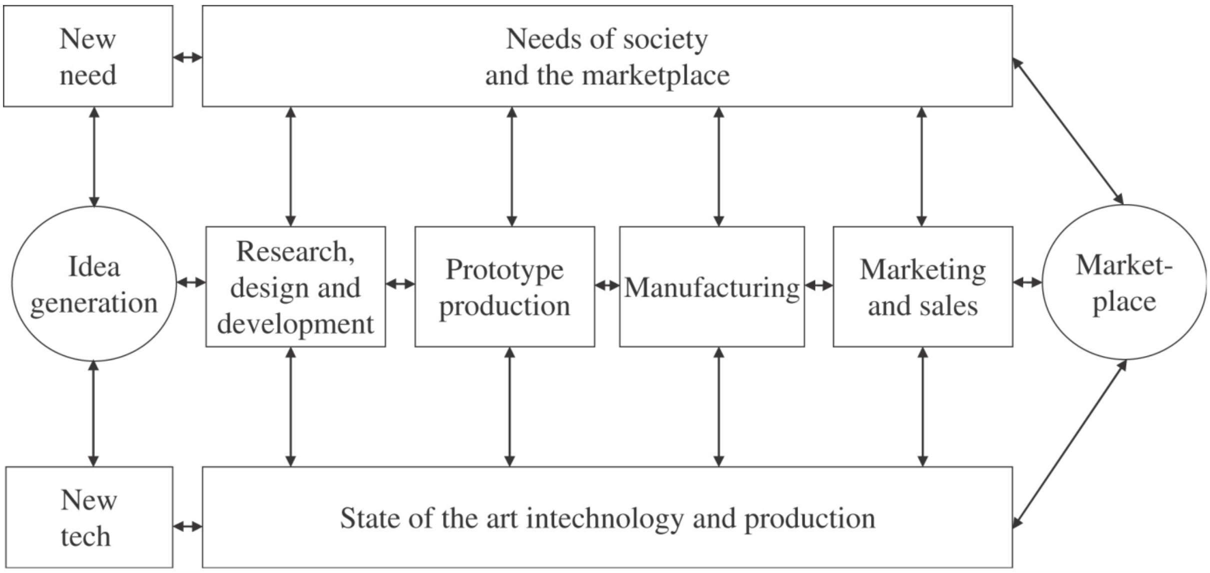

Figure 2.4 - Interactive Model

2.3.3.4 4th Generation - Integrated Models (1980s-1990s)

The fourth generation model is a further development of the Simultaneous Coupling Models. Although, the third generation models were non-linear, they were criticised for being fundamentally sequential in nature (Rothwell, 1993 as cited by Hobday, 2005). After recovering from the economic crisis in 1980s, the focus shifted towards parallel and integrated products processes development. The companies started building strong linkages with supplier as well as close connections with valuable customers. Japanese automobile manufacturers were highly successful in parallel and integrated product development approach and were able to achieve significant success in minimising the new car development process from 4-5 years to under 3 years (Bochm and Frederick, 2010). This move gave a birth to fourth generation innovation models, called Integrated Models. These models proposed to have functional overlaps between departments and/or activities as well as cross functional integration at internal and external levels which included suppliers, customers, universities and government agencies (Hobday, 2005). An example of the

Integrated model taken from Rothwell (1993, Ref. 7, p. 22 as cited by Hobday, 2005) is presented in the figure below.

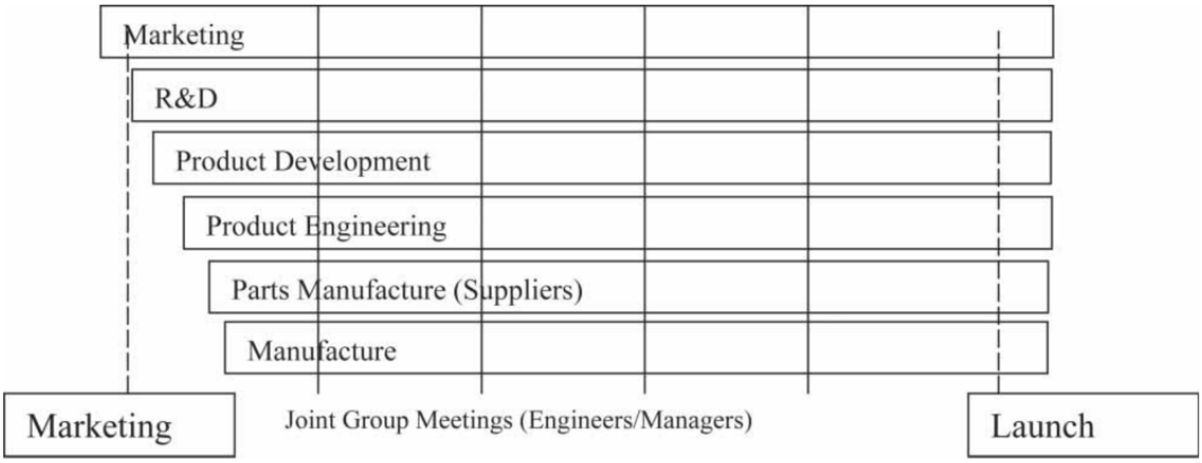

Figure 2.5 - An integrated (fourth generation) innovation model

2.3.3.5 5th Generation - Network Model (1990s – onwards)

The 5th generation network model can be described as a fully integrated model that facilitates parallel development with the support of advanced information technology. It was developed in 2000, and has strong linkage with extended members of networked enterprises such as customers, suppliers, distributors etc. who have great influence on the innovation processes. The diagram below taken from Trott (2002); outlines the connection with external actors. It can be noted that external inputs have a direct effect on each business functions i.e. Finance, Research and Development, Engineering and Manufacturing, and Marketing and Sales. This seamless integration between and within each function facilitates the generation of knowledge and supports fostering of new innovative ideas.

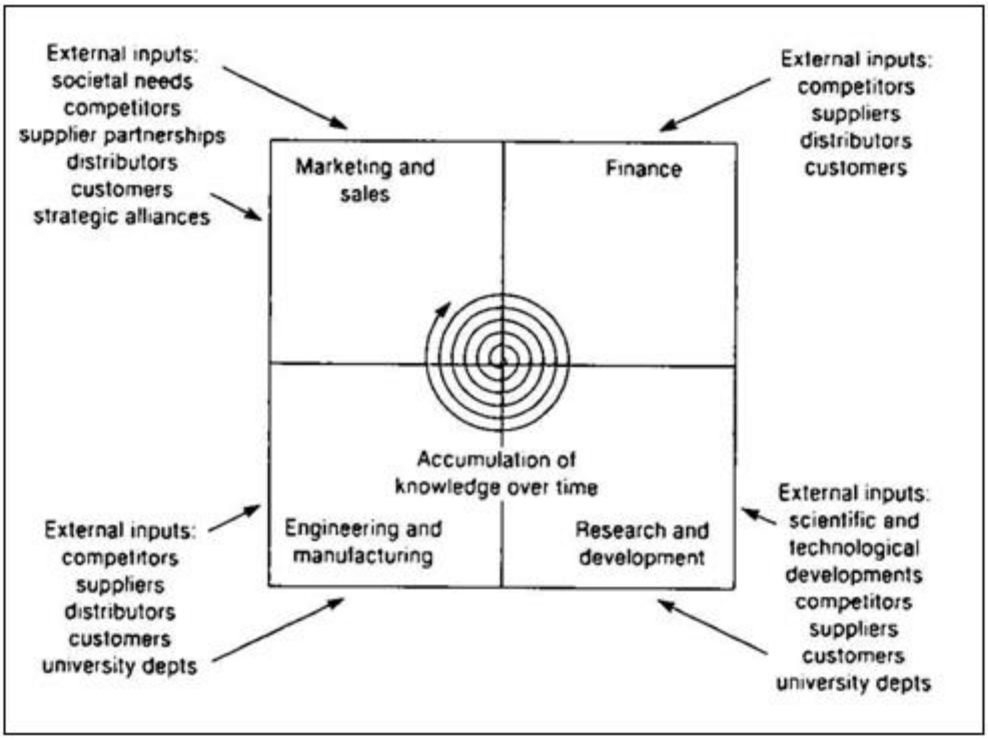

Figure 2.6 - Network Model of New Product Development

Overall, it can be concluded that the innovation processes have been evolved from linear to interactive over time. In this evolution process, each generation served as a foundation for the design and development of new models by integrating new inputs and factors significant to the innovation process. Hobday (2005) criticised the above models for being oriented towards large firms (i.e. organisation with R&D department) rather than SMEs (with no dedicated R&D department) and mainly dealing with R&D-centred activities. In addition, these models are not suitable for catch up innovation scenarios where the companies make minor improvements to their existing products and processes based on the assimilation technology from other organisations (Hobday (2005).

Today's complex manufacturing conditions and highly dynamic customers' demands require a more sophisticated innovation framework to handle it. One possible way to address this could be by integrating knowledge in every stage of the innovation process and creating a supportive environment where an individual can learn about the company's products, processes, principles and practices, innovation goals and objectives etc. The individuals can then utilise this information and knowledge in their daily activities to generate innovative ideas. To achieve this, the companies will require to develop organisational memory in the form of a repository or database where they store all their past and current knowledge.

To this end, the research now focuses on understanding how knowledge is defined in literature, existing knowledge modelling methods and methodologies to support the design and development of the intended knowledge repository.

2.4 Knowledge Management

The literature on Knowledge Management (KM) in SMEs is stated as fragmented by Massaro et al. (2016), who found only "few specialised authors" publishing their work in this field and stated it is "dominated by unrelated research mainly originating in other contexts (e.g. larger organisations)". The researchers (Massaro et al., 2016) discovered only "few comparative studies between countries, and with limited studies in important developed countries (e.g. USA and Canada) and some continents almost ignored (e.g. Africa)." In their review, the Massaro et al. (2016) noted that "different definitions of SMEs are used and different kinds of organisations (e.g. micro, small and medium) are sometimes treated as equivalent" which makes the "comparisons between studies hard". Despite the fact that literature on KM is dominated by publications on large organisations, the medium-sized firms are the ones which are least investigated and therefore needed more attention by the scholars and practitioners in this field (Massaro et al., 2016).

This research programme focuses on the knowledge management practices of small and medium sized manufacturing enterprises and discusses them in detail in Chapter 4. The next section provides general explanation of what is a knowledge and refers to different knowledge modelling approaches.

2.4.1 Definition of Knowledge

There is no single globally accepted definition of the term “knowledge”. It can be defined as refined information which a person or an organisation gained through experience. Different researchers define it differently. Some of the most commonly used definitions are:

- *"Knowledge is information combined with experience, context, interpretation, and reflection. It is a high-value form of information that is ready to apply to decisions and actions." (Davenport et al., 1998, pp. 43)*

- *Knowledge is “information evaluated and organized by the human mind so that it can be used purposefully, e.g., conclusions or explanations." (Rousa, 2002, pp. 283).*

- *Knowledge is “human expertise stored in a person’s mind, gained through experience, and interaction with the person’s environment." (Sunassee and Sewry, 2003, pp. 25)*

In Cambridge dictionary, it is defined as “*understanding of or information about a subject which a person gets by experience or study, and which is either in a person's mind or known by people generally*”. Sometimes people use the term knowledge and information interchangeably. Foskett (1982) argues that both terms are different from each other and have their own meaning. According to Foskett (1982), *“Knowledge is what I know, Information is what we know."*

In this knowledge economy, manufacturing organisations are highly dependent on knowledge in order to effectively manage their innovation processes and to make them more efficient. In

Innovation context, the knowledge can be defined as useful information about ideas and their selection for implementation; information about company's products and processes, current and past projects both successful as well as failed projects; information about resources available for innovation projects, company's principles and policies, etc. For knowledge to be useful, it is important that it is available to all the actors during innovation process. The knowledge accuracy, effectiveness and accessibility are also important. This is where the knowledge management concept comes into action. Blake (1998) has defined knowledge management as *"process of capturing a company's collective expertise wherever it resides and distributing it to wherever it can help produce the biggest payoffs"*.

It is highly important to store this information in such a way that it can easily be consulted and reused in future developments and projects e.g. the knowledge about successful and unsuccessful projects can be consulted and used as a benchmark for making decisions on new projects in same domain.

There are many commercial products available to capture knowledge such as Siemens' 3i (Ideas, Impulses, and Initiatives) or Chrysler's EBOK (Engineering Book of Knowledge). Most of the systems use heuristic methods to support knowledge capturing. However, there are no tools in the market for effectively collecting ideas, identifying needs and knowledge which can be adapted for SMEs. Current methods do not provide means to motivate and help people come up with ideas within an Extended Enterprise Context, or they are too elaborated for SMEs. Moreover, they do not properly support re-use and sharing of knowledge among different players within the extended SMEs, and their maintenance often requires knowledge-system specialists.

2.4.2 Knowledge Modelling

Knowledge Modelling is a *"systematic approach to understanding, discovering and codifying the information, workflows, history and relationships inherent in today's complex and rapidly changing business environment*" (Philip and Reid, 2006). In present hyper-competitive economic playground where available data sources, business methodologies and processes are extremely complex, evolving and vastly distributed; knowledge modelling application can be a valuable weapon for SMEs to compete with big organisations.

2.4.2.1 Knowledge Engineering Methodologies

Amongst the large number of knowledge Modelling techniques, the most popular are:

- CommonKADS
- Unified Modelling Language (UML)
- MOKA
- Protégé

They are described in detail in the following sections.

2.4.2.1.1 CommonKADS

CommonKADS methodology provides a systematic way to develop Knowledge-Based Systems (KBS). It supports most aspects of KBS development project such as Knowledge acquisition; Knowledge analysis and modelling; Knowledge system design (Gohain and Jayam, 2013). The process includes analysis and transformation of expert knowledge into a format exploitable by the computers. Several examples have been reported in the literature by Prat et al. (2012) where CommonKADS have been applied in various domains e.g. web-based expert systems development; knowledge-based approach to supervised classifier design; knowledge-based system to diagnose breast cancer.

2.4.2.1.2 Unified Modelling Language (UML)

UML is a unification of Jacobson's Object-Oriented Software Engineering, Rumbaugh's Object Modelling Technique and Booch's method; and defined as a de-facto standard for object modelling (Abdullah, 2006). During early days, UML was mainly used by the software development community. Now, it has been applied in a range of applications in various domains such as modelling object tracking in video, in mechatronic to validate and verify the conceptual robot design; capturing software perspective of Cyber Physical Systems applications; modelling distributed and parallel applications (Uke and Thool, 2016). Extensive amount of work has been carried out by researchers to develop UML extension for knowledge modelling (Abdullah, 2006).

2.4.2.1.3 MOKA

MOKA methodology is used for developing Knowledge-Based Engineering applications for capturing and applying knowledge in complex design processes; specifically developed for applications within aeronautical and automotive industries. MOKA proposes Formal and Informal Models for the Knowledge-Based Engineering (KBE) application development lifecycle. It has been reported that MOKA *"reduces the lead times and associated costs of developing KBE applications by 20 - 25% and provides a consistent way of developing and maintaining KBE applications"* (Gohain and Jayam, 2013).

2.4.2.1.4 Protégé

Protégé is a modelling technique which was developed for domain specific applications. The Protégé 2000 provides a frame-based ontology editing tool and knowledge acquisition tool for domain modelling (Noy et al., 2000). The ontology has classes, slots, facets and axioms. The Protégé supports the development of Knowledge-Based systems by the reuse of problem solving methods and ontologies (Gohain and Jayam, 2013).

2.4.3 Methods for Knowledge Storage and Utilisation

Over the past decade the ability to innovate both products and processes has become a significant driver of competitiveness within global markets, i.e. it has become the next way forward for companies, both to survive and to compete in the hyper-competitive economic environments (Flynn et al., 2003; Trott, 2008). The importance of new product ideas is emphasized by the fact that the improvements in idea generation greatly influence the following new product development stages (Montoya-Weiss, and O'driscoll, 2000; Toubia, 2006). Companies mainly generate multiple product ideas in the early phase of innovation (i.e., Inception or ideation stage) and keep only few of these ideas for the subsequent phases (Griffin, 1997). Additionally, a study by Griffin (1997) states that “100 ideas lead to 15.2 successes.” These evidences together suggests the crucial effects of product ideas on NPD success, and a best practice study (Barczak et al., 2009) urges further knowledge improvement in idea management. Here Li and Xu (2008) stated that there is still a need for centralised system or platform to systematically manage the innovation process and both proposing the need for a Knowledge Base as a key element of the innovation platform which handles the knowledge acquisition, classification, organisation, storage, transmission, maintenance and sharing of the highly diverse types of data involved in the innovation processes and activities within manufacturing SMEs.

Literature has exemplified number of design methods which can be used for the design and development of knowledge base for knowledge storage and utilisation. The following are the most popular and currently being used by many idea and innovation management applications/projects:

1. Ontology

2. Case Based Reasoning

2.4.3.1 Ontology

With the introduction of Semantic Web, new ways of data storage and processing came into existence. Ontology, one of the basic components of semantic web, has been widely used in the area of knowledge management.

There is no mutually agreed definition of ontology; however, in philosophy, ontology is defined as "*a theory about the nature of existence, of what types of things exists; ontology as a discipline studies such theories"* (Lee et al., 2001). Ontology provides a shared understanding of specific domain readable by both humans and machines (Ning et al., 2006). It is made up of classes, properties, relationships and axioms.

Several attempts have been made for managing idea and innovation using Ontologies (Bullinger, 2008; Riedl et al., 2009; Westerski et al., 2010). Ning et al. (2006) introduced a vision of Semantic Innovation Management System powered by Ontology, Inference and Mediation technologies to create semantic web of innovation knowledge. He applied metadata harvesting and RDF access technologies to design and develop the functional framework of his system. However, the paper does not contain detailed explanation of the concept he applied in the development of the proposed ontology. Moreover, the direct access is also not provided to the ontology.

In a recent study on innovation Ontology, Bullinger (2008) developed Ontology, called OntoGate, which models idea assessment and selection process of innovation management at company specific level. It also provides appropriate structure to each element of innovation process such as inputs, outputs and actors. For example, the idea collection activity involves input from different actors such as internal and external actors, employees and executives and so forth. Internal and external actors are further broken down into sub-categories such as continuous internal input and discontinuous internal input. This results in better understanding of the structure of innovation process. However, the presented research work has few areas for improvement. Firstly, it does not provide a data model for representing an individual idea. Secondly, it is limited to idea assessment and selection process of innovation process and does not support interoperability between innovation tools and applications.

In contrast to OntoGate, Riedl et al. (2009) has proposed an OWL-based Idea ontology that defines a common language for innovation processes. It provides means for storing and exchanging ideas among different innovation tools and support interoperability. Riedl et al. (2009) has emphasized that the existing Ontologies e.g. FOAF, can be reused to achieve interoperability among other general applications such as social networking sites.

There are number of benefits of using ontology in innovation management applications for instance:

- Allows people and software agents to have shared view of structure of information.
- Facilitate separation of domain knowledge and operational knowledge.
- Domain knowledge can be reused.
- Provide structure to unstructured or poorly structured data (Noy and McGuinnes, 2001; Sure et al., 2003; Husemann and Vossen, 2005; Bullinger, 2008).

2.4.3.2 Case Based Reasoning

Case Based Reasoning (CBR) is a method of solving new problems by using the information and knowledge of similar cases captured and learned in the past (Aamodt and Plaza, 1994). In CBR approach, when problem occurs, existing solutions are analysed to find similar pattern. If one or more cases match with this problem, then those cases are extracted and analysed to find solution to the problem. Once the problem is successfully solved, these cases are revised and stored with new experience gained for future use. On the contrary, if the attempt fails then the reasons of the failures are identified and retained to avoid future mistakes.

Literature has exemplified number of studies where CBR has been applied in Innovation and Knowledge Management research projects. For example, AIMs project applied CBR in the Collection System, with the objective to search problems and/or ideas, based on similarity criteria (Sorli et al., 2006). Another study by Robles et al. (2006) demonstrated CBR applications to support innovation and knowledge capitalisation process. Researchers have also applied CBR to support design, knowledge management and equipment selection activities in the literature (Braunschweig and Surma, 1996; Watson, 2001; Avramenko et al., 2004).

How does CBR Works?

The CBR process life cycle can be decomposed into four activities:

1. Retrieve
2. Reuse
3. Revise
4. Retain (Aamodt and Plaza, 1994)

When a problem arises, similar cases are accessed and searched to *retrieve* previously experienced cases, *reuse* the experience to get the solution to a new problem, revise it with the new experience gained, and finally *retain* the parts of new experience and incorporate it into the existing repository for future use. The following diagram demonstrates the whole life cycle of CBR process:

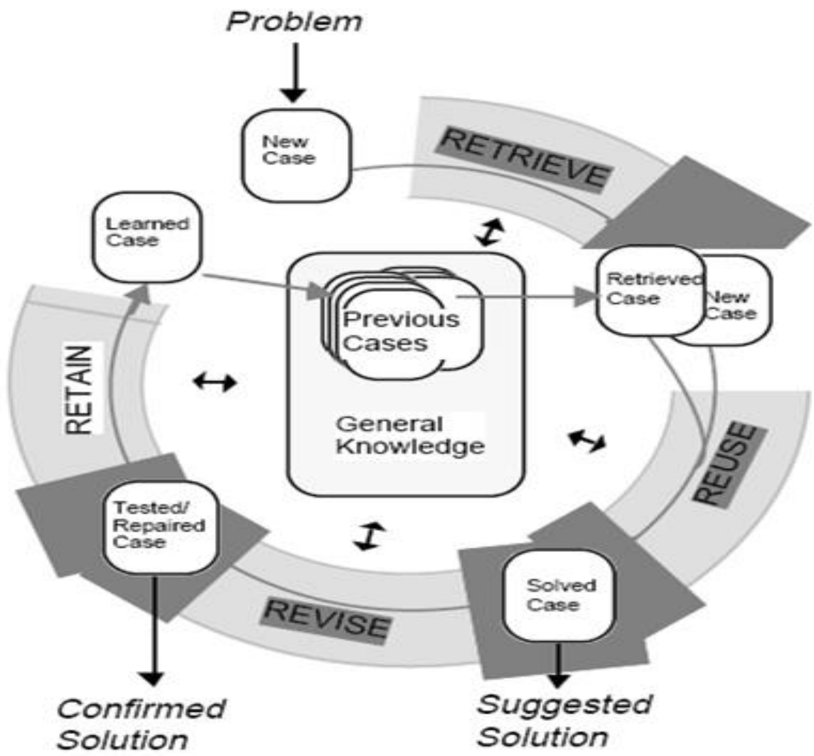

Figure 2.7 - CBR Cycle

(Picture source: Aamodt and Plaza, 1994)

Apart from its numerous advantages, CBR also has few disadvantages. Robles et al. (2006) stated that CBR's power (i.e. CBR memory) is its greatest weakness. As CBR completely depends on its memory, therefore if the memory is empty or if the problem is encountered for the first time then the CBR based system won't be able to provide any efficient solution.

2.5 Learning Organisation

2.5.1 Definition

The Learning Organisation philosophy promotes learning in an organisation with the aim to achieve continuous improvement. It facilitates learning of employees and continuously transforms itself (Pedler et al., 1989). It emerged in late 1970s. In 1979 Huczynski and

Boody (as cited by (Ortenblad, 2018) were referring to Learning Organisation as “organised learning, that is, the organisation of certain learning activities”. The term learning organisation” could have been developed from paraphrasing of the term “organisational learning” which “occurred in works that are known to be about organisational learning (Argyris and Schön, 1978, p. 111; Hedberg, 1981, p. 22; Dery, 1982; Peters and Waterman, 1982, p. 110)” as cited by (Ortenblad, 2018). However, the term learning organisation was coined by Senge (1990) in his best-selling book The Fifth Discipline: The Art and Practice of the Learning Organization (Senge, 1990). Senge (1990) described learning organisation as “organisations where people continually expand their capacity to create the results they truly desire, where new and expansive patterns of thinking are nurtured, where collective aspiration is set free, and where people are continually learning how to learn together”. From this definition, it can be stated that the learning organisation is a team and continuous organisation process that can empower companies to respond to the organisational challenges due to the shift from industrial-based economy to information-based economy.

Generally two viewpoints have been presented in the literature. The first viewpoint expressed by Marquardt and Reynold (1994), define it from systems viewpoint:

> *"A learning organisation is systematic, accelerated learning that is accomplished by organisational system as a whole rather than the learning of individual members within the system. Learning organisations are able to transform data into value knowledge and thereby increase the long-term adaptive capacity." (Marquardt and Reynold, 1994)*

The second one is slightly different from the previous viewpoint which describes it as

"A Learning Organisation is one which has a vision of tomorrow, seeing the people who make up the organisation not simply being trained and developed to meet the organisation's ends in a limiting and prescriptive manner, but for a more expanded role.... Empowerment raises crucial issues concerning leadership, decision-making, and the ownership of activities and their results. It is these issues which lie at the heart of the Learning Organisation." (Stahl et al., 1993)

Thus, it can be stated that the Learning Organisations are mainly about empowering workforce and making learning as a part of their daily routine. By implementing learning as a means of doing things, the organisation can effectively tackle following three challenges (Davies and Longworth, 1996):

- Retraining and redeploying workforces due to changing technology and new working requirements.
- Inefficient and ineffectual hierarchical management structure to respond to competitive market place and shorter product lead times.
- *"The new corporate imperative to downsize and keep a core staff, bringing in expertise as required, demanded a much higher level of education and operation in existing staff and suppliers." (Davies and Longworth, 1996)*

2.5.2 Characteristics of Learning Organisation

According to Senge (1990), Learning Organisations have following characteristics. They:

- Decentralize organisation (especially the role of leadership) with a view to enhance employee productivity towards common goals.
- Employ a holistic approach, systems and structure for sustainability by focusing organisation efforts to achieve shared goal.

- Promote idea of informal social networks to boost performance, learning, and innovation.
- Are master in five disciplines: System thinking, Personal mastery, Mental model, Building shared vision, and Team learning.

Literature has reported several benefits of Learning Organisation. According to Garvin (1993), it masters the firm in five activities:

- Applying systematic approach to problem solving
- Experimentations with new approach/methods/tools
- Managing knowledge gained from experiences and past cases to promote learning
- Acquire knowledge from external sources such as best practices of others, and apply in the organisation
- Ability to quickly and efficiently share knowledge from all sources (both internal and external) throughout the organisation

2.5.3 Learning Organisation and Innovation

In today's knowledge-based economy, learning is essential for organisations to stay up-to-date with highly dynamic market conditions and to take proactive actions to meet ever-changing customers' demand. However, learning culture itself won't be enough to gain competitive advantage in this highly competitive economic playground. Due to the low-cost competition from East and technological pressure from the big players, it is important for SMEs to apply creative thinking and introduce innovation in employees' daily work-related activities as well as products and services.

The research has shown that the integration of Learning Organisation practices and Innovation Management principles has a positive effect on firm’s innovation effectiveness

(Han et al., 1998; Baker and Sinkula, 1999, 2002; Hurley and Hult, 1998;). Therefore, the seamless integration of these two concepts can increase survival chances of manufacturing SMEs and can also take innovation capacity of organisations to the next level.

It should be noted that innovation is defined as a risky game. With successful integration of Learning Organisation concept, innovation can reduce its riskiness. However, innovation also has several pre-requisites that a firm should fulfil for its successful implementation and execution. Researchers have highlighted that innovation culture is a paramount requirement for innovation to foster; and it also requires that cultural values foster learning (Mumford, 2000; Medina et al., 2005, Lin and Chen, 2006). However, stimulating organisation-wide learning culture is a challenging task. Literature has urged the need for development of an effective organisation learning process in the firm to encourage learning (Jimenez-Jimenez and Sanz-Valle, 2011).

2.6 Quality Circle Programme

Quality Circle Programme is a management technique that has dominated the Total Quality Management era. The Quality Circle concept was originated and developed in Japan around 1962 and was then spread across other parts of the world.

Definition of Quality circle:

> *"A small group between three and twelve people who do the same or similar work, voluntarily meeting together regularly for about an hour per week in paid time, usually under the leadership of their own supervisor, and trained to identify, analyse, and solve some of the problems in their work, presenting solutions to management, and where possible, implementing the solutions themselves." (Hutchins, 1985, pp. 188)*

According to Hutchins (1985), a quality circle is a small group of people from same work place who come together within paid working hours to solve work related problems. The group work under the supervision of their own supervisor thus reduces the risk of supervisor feeling unsecure regarding his position in the company. Training is an essential part of quality circle programme. All the participants are given opportunity to learn new skills to identify, analyse and solve problems and/or presents solution to senior management.

There are enormous advantages of quality circles programmes reported in the literature. Especially, the problem-solving aspect of the programme has been highly appreciated by the researchers and industry. However, today's hyper competitive environment, increasing threat from lower-cost economies and other high-tech rivals, demands innovation rather than merely solving problems. Additionally, the downturn in recent years (2007 – 2009) has made the situation of EU companies even worse.

To address above mentioned issues, the academics and practitioners in this field proposed a new framework which is implanted by coupling the Innovation Management principles and Quality Circle programme's best practices (Tan, 2007; Alasoini et al., 2008). The next section provides detailed overview on this framework.

2.6.1 Innovation Quality Circle

Innovation Quality Circle (IQC) is a next generation of traditional quality circle programme build on combination of both IM principles (Smith and Ainsworth, 1993) and Quality circle best practices (Hutchins, 1985). It can be defined as:

> "*Small group of people from same work place coming together in paid working hours to explore opportunities with the ultimate aim of making a significant difference through innovative thinking and to make recommendation to senior management*"

The basic idea of IQC approach is to enable everyone to take responsibilities, be fully involved in continuous learning and improvement activities, searching new business opportunities, and organisational problem solving activities. The IQC has some similarities with traditional Quality Circle Programme in which a small group of people with diverse backgrounds come together in paid working hours, to identify, analyse, and solve organisational problems, by presenting possible solutions to senior management, and if permitted, implementing the proposed solutions (Hutchins, 1985). However, there are significant differences between two concepts. Whereas, QCP is a reactive approach focused on solving existing problems, on the contrary IQC is a proactive approach which tends to explore new opportunities. The key differences between traditional and new Innovative quality circle are outlined in Table 2.2 (Tan, 2007 as cited by Alasoini et al., 2008).

Table 2.2 - Comparison between Quality Circle and Innovative Quality Circle

Traditional Quality Circles	**Innovation Quality Circles**
Reactive: Address existing problems	Proactive: Explore new opportunities
Conventional: Solve problems and streamline standard operating procedures	Innovative: Focus on outcomes and question existing standard operating procedures
Rigid: Members from same work area	Openness: Cross- or multi-functional teams
Prescribed PDCA (Plan, Do, Check, Action) approach and specific tools to be Used	Flexibility to use any appropriate approaches and tools

(Source: Tan, 2007 as cited by Alasoin et al. 2008)

The traditional quality circle thinking has been criticised for being too narrow and primarily focused on addressing industrial mass production problems. In this current knowledge-based era, companies have to continuously keep hunting for new opportunities to gain competitive advantage, which led to shift of focus from process development to continuous generation of innovation. The IQC approach is primarily design to address these issues, and provide flexibility to work with cross functional teams to explore new opportunities and innovation solutions.

2.6.2 IQC Organisation Structure

The core of IQC structure is derived by linking traditional Quality Circle structure (Udpa, 1990) and IM principles (Smith and Ainsworth, 1993). The hierarchal design of IQC structure is depicted in Figure 2.8. The role and responsibilities of each personal in IQC organisation is presented in following sections.

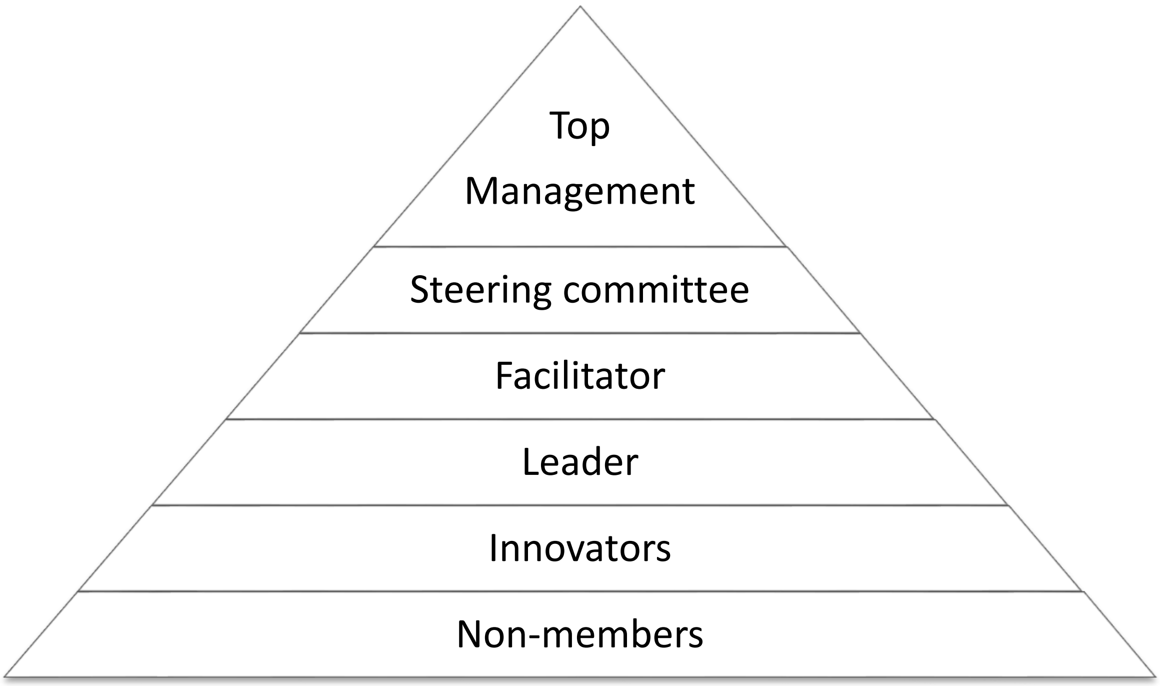

Figure 2.8 - Organisation Structure of IQC

Top Management

Top management provide necessary resources and environment to foster IQC in organisation. Without full support from Top management, IQC success is uncertain.

Steering Committee

Steering committee is composed of senior managers, head of departments and other key personnel in the organisation. The main job of the committee is to make sure the IQC members get all the necessary support and it is also responsible for introducing learning programmes to boost creativity and innovation capacity of the employees. It also monitors IQC group progress and provide feedback and suggestions.

Facilitator

The facilitator is usually the most trusted person of the management. They acts as a mediator between management and employees. The facilitator's main duty is to identify the training needs of employees in order to develop idea generation, self-evaluation and creativity skills.

Leader

As the name suggests, the Leader leads the IQC team in its innovation activities. One of the foremost tasks of the Leader is to organise regular IQC meetings and make sure all the members get equal opportunity to present their innovative ideas and express their views in IQC group discussions.

Innovators/Members

Innovators are the main elements of IQC structure. They are the personnel working in same work-place with similar goals and objectives. They meet voluntary in paid working hours to identify new opportunities, generate ideas, and discuss them with other innovators of IQC team and finally present potential ideas/solutions to senior management.

Non-members

These are all other members of the organisation who are not directly part of IQC group. They can be invited into IQC meetings to provide required support/information and/or expert opinion to IQC team.

2.7 Summary

Chapter 2 has covered extensive review of published work in the area of Innovation Management, Knowledge Management, Learning Organisation and Quality Circle that supports and argues the reasoning for conducting this research. The chapter starts with a brief overview of manufacturing industry before moving to define the problems and issues faced by companies in this sector. The review then looked at how innovation is defined in the literature and evaluated existing innovation models.

The chapter has covered the broad topic of Knowledge Management. Undoubtedly, the large amount of research has been published on Knowledge Management, but the author has found some areas, such as knowledge storage and knowledge utilisation from SMEs' perspective, are lightly researched. Therefore, the research objectives especially Objective 3, 4, 5 and 6 are aimed to address this gap. The results of these objectives, as described in Chapter 4, make novel contributions to the existing knowledge in this area.

The other limitations that were found in the literature are as follows:

- Compare to large organisations, the publications concerning methods, approaches and/or methodologies to support innovation processes in SMEs form a small portion of the total published work in this area.
- Most of the methods, approaches and/or methodologies proposed to support SMEs' innovation processes were originally developed and implemented at the large organisations and do not take into account the environment in which SMEs are operating.
- The existing innovation systems are mainly focused on the management of innovative ideas. There is no way for employees to look for information and knowledge to self-validate their idea and check if it is in-line with related principles and practices. Therefore, there is a need to investigate the development of a knowledge repository which can be referred to at any stage of the innovation process.
- Literature review has highlighted that Knowledge Management has positive impact on the firm's innovation capability. However, only few examples are found discussing conceptual models combining both methodologies. Further research is required to investigate the design and development of combinatorial framework to provide insight into integration of these approaches. The current literature only discussed conceptual models and does not provide any examples of implementation and feasibility of such arrangements in the real industrial environment.

Finally, the chapter has provided an overview of Learning Organisation and Quality Circle approaches and briefly discussed their impact on the innovation ability of an organisation.

The next chapter describes the methodology that has been applied to achieve the aims and objectives defined in Chapter 1 and fill the gaps identified in the current literature.

CHAPTER 3 - RESEARCH METHODS AND METHODOLOGIES

3.1 Introduction

The literature review has shown a positive impact of Knowledge Management on the Innovation processes. As the creation and utilisation of knowledge repository in innovation processes in manufacturing SMEs form the basis of this research, it is important to choose the research methodology that supports the achievement of the research aims and objectives defined earlier in Chapter 1. This chapter provides an overview of potential research methods and methodologies and describes in detail the strategy applied to conduct the research. It outlines the steps undertaken to build the chosen research methodology.

3.2 Research Philosophies

Research can be defined as a systematic process of investigating or to study a subject, material or issue to draw new conclusions. This is usually structured by transforming problem into series of questions, with aim of finding answers to the questions. It applies scientific methods to gather data, analysis it and reach conclusions. Goddard and Melville (2004) stated that the research is not just about collecting and analysing data, it also widen the limits of our ignorance.

The selection of methods and methodology has a greater impact on research outcomes. Therefore, it is important to choose right research methods to undertake the research. There is also a significant difference between the terms research methods and research methodologies. Research Methodology is a systematic approach to conduct an effective research study and to gather valuable information to support the research. Davy and Valecillos (2009) defined the research methodology as *"the systematic collection and analysis of observations for the purpose of creating new knowledge that can inform actions and decisions."*

Whereas, Methods can be defined as a research tool that helps in gathering data and information and used as a basis for interpreting research issue (Cohen and Manion, 1994). According to Kaplan (1973) research methods are primarily about techniques used to collect data and its analysis; and methodologies described the research methods' limitations, strengths and weaknesses.

Researchers have also described research methods as a logic; the logic at the time of defining the research problem, the formulation of the hypothesis, the data collection technique, and the analysis of the data. There are three types of research methods:

- ***"Quantitative",***
- ***"Qualitative"*** and
- ***"Triangulation"*** (Creswell, 2003).

3.3 Research Methodology

This research has used the Triangulation research method. Triangulation actually means that two methods of data collection will be used in a research programme to validate the data. The intention here is to use both primary and secondary data and complement it by at least another primary method of data collection independent from the first primary research. The research programme requires use of both qualitative and quantitative research. Thus, the proposed research methods have taken potential benefits of both approaches and overcome the potential bias of single or dual means of data collection.

The main aim of the research, as described in Chapter 1, is to investigate the viability of the design and development of a knowledge repository to support innovation processes in manufacturing SMEs. To achieve this aim, a series of tasks were planned to explore what companies understand by innovation, and how they carry out innovation activities in the company. Initially, the data was collected from the literature review and an iterative primary research was conducted through periodic meetings with collaborators as the research is a part of prestigious EU funded ExtremeFactories project.

Based on the responses received, a structured questionnaire has been designed to gather data appropriate to carry out the intended investigation with a view to achieve the research aims. It is further followed up with interviews with the managers. The research has acquired business cases from the selected manufacturing companies and again the interviews have been carried out with the concerned personnel.

At the end of the data collection stage, the collected data is analysed using appropriate analysis techniques based on attributes identified in the literature research to design the structure of the CKR to support innovation processes. As a result, the CKR has been developed to store the knowledge related to innovation activities in the company.

A number of activities have been planned to demonstrate that all the user requirements are met for both the framework and the intended repository. In order to demonstrate the validity of these requirements a set of test cases are designed. These test cases include a number of scripts and test data (data which is used to validate the repository). In each test case, the actual output and the expected output are analysed. If both fall within the assigned tolerances levels, the test case is considered valid and therefore the requirements identified for such a test case are also to be considered valid.

To summarise, the research methodology includes:

1. Extensive literature review of existing innovation models, knowledge management, alternative techniques for the design and development of the CKR, Learning Organisation and Quality Circle Programme.
2. Preliminary data collection by meetings with collaborators.
3. Data collection through structured questionnaires and follow-up interviews with managers of manufacturing companies.
4. Data collections through case studies and follow up interviews with the concerned personnel within the selected businesses.
5. Analysis of the data collected using questionnaires, interviews and case studies and its use for the design and development of the novel innovation framework and CKR.
6. Validation of the proposed framework and repository.

3.4 Research Framework

As previously mentioned, this research has applied the triangulation research approach, the methods of data collection in relation to the research aims and objectives (in Chapter 1) are discussed. This approach is advised by (Durst and Edvardsson, 2012) over mono method approaches, to obtain a greater understanding of KM and innovation process in SMEs.

3.4.1 Industrial Survey

In order to get a broader view of the Innovation processes in manufacturing SMEs, the Industrial survey approach is applied. In industrial survey research, Questionnaires are the most commonly used tool to gather data. However, the reliability and validity of the research outcomes highly depend on how the questionnaire is written. Shaughnessy et al., (2011) suggest six steps that can be applied to construct a questionnaire to produce reliable and valid results.

1. **Decide what kind of information should be collected**

   As mentioned earlier, the objective of the industrial survey was to get a broader view of the innovation and knowledge management processes in manufacturing companies to achieve the objectives of the research programme defined in Chapter 1. To this end, the questionnaire was composed to a) understand how companies come up with new ideas; methods and tools used in idea generations; b) investigate how they apply knowledge related to principles and practices in the innovation process; and methods used to store such knowledge.

2. **Decide how to conduct the questionnaire**

   As the objective was to reach a wider audience to get a general view of their innovation and knowledge management practices, therefore the online survey approach is used to conduct the survey. This approach has greater advantages over traditional approaches of surveys such as the telephone-based survey, mail (post), personal in-home surveys, personal mall or street intercept survey. Online survey allows respondents to answer the questionnaire according to their own pace and chosen time. As the data collection and storage process is automatically handled by the computer server, therefore, there is less possibility of data errors.

   The Google Forms are used to construct the online survey. This is a free tool to collect and organise information with real-time response info and charts.

   Several methods are used to distribute the questionnaire.

i) Emails were sent to participants. As a benefit of working at Centre for Factories of the Future, the researcher has access to a database of companies. The link to participate in the online survey was shared with all companies in the database using emails.

ii) Link of online survey was shared through LinkedIn (See Appendix B - LinkedIn Post content for content of LinkedIn post).

iii) Article was posted in Greater Birmingham Chambers of Commerce weekly e-newsletter which was sent to a database of 32917 email addresses of companies.

3. Construct the first draft

Following the guidelines of an ideal questionnaire by (Davidson, 1970), questionnaire format by (Tourangeau et al., 2000) and style by (Bradburn et al, 2004), the first draft was produced and shared with the supervisory team to review and provide feedback

4. Revise the questionnaire

The comments and suggestions received from the supervisory team were implemented and a new version of the questionnaire was produced.

5. Pre-test the questionnaire

The revised version of the questionnaire was published online using Google Forms. The link of the questionnaire was sent to selected industrial partners for pretesting. The criteria of assessment include:

i) Are the questions easy to understand?

ii) Is the technology and interface easy to use?

iii) Is the questionnaire length appropriate?

iv) Is the complicated syntax avoided?

v) Are vague concepts avoided, or are examples provided for such concepts?

vi) Is the time taken to complete the survey appropriate?

6. **Edit the questionnaire and specify the procedures for its use**

   Based on the feedback, the questionnaire was modified, and the final version was published online and shared with the target audience using means specified in the previous step.

By following the above-mentioned practices, a preliminary questionnaire was designed (see Appendix A). The questionnaire is aimed to:

- Get familiar with companies' product and services.
- Evaluate current practices for storing documents used in the innovation processes e.g. principles and practices.
- Discover information and knowledge sources used in the innovation processes.
- Identify current tools being used by companies to store information and knowledge.
- Identify factors that hamper knowledge storage and utilisation in SMEs.
- Discover formats the information and knowledge sources are available in.

The results of the preliminary questionnaire are discussed in Chapter 4.

3.4.2 Case Studies

As a part of this research programme, two case studies of manufacturing SMEs: Mb Air Systems limited (MBAS), Charles Robinson Cutting Tools Ltd (CTOOLS) were carried out. This study applied the Explanatory approach, also known as Intrinsic approach. The key objectives of this study were to explore the current practices to manage innovation processes in the manufacturing companies; the methods/procedures for collecting and storing innovation related knowledge; the tools used in coming up with new ideas for improvement or new products/services/processes introduction.

Centre for Factories of the Future Ltd, where the researcher is working full time, has a database of manufacturing case studies in the area of Innovation and Knowledge Management. Being a part of the team, researcher has access to this repository. The case studies relevant to the field of study were reviewed from this database. In addition, being a part of the EU funded ExtremeFactories project, researcher was directly involved in preparing case studies in 7 industrial manufacturing SMEs from 4 European countries. These case studies were used in the design and development of intended knowledge-based innovation framework. Having multiple cases from companies from different fields helped the research to have sound basis for generalisations of findings and conclusions.

3.4.3 Interviews

The semi-structured interviews approach was used in the data collection. A series of questions to understand innovation and knowledge management practices were prepared. The interviews were carried out with managers, directors and engineers working in participant companies to explore their perspectives on innovation and knowledge storage and utilisation practices in their organisations. All the participants were made clear about the objectives of the research and were asked to provide their consent before the interview.

The interviews were carried out at different stages of the research programme. These are explained below:

1. **Validation of research problem**

   In stage 1, the interviews were conducted with directors and research managers to validate the research idea, aim and objectives.

2. **Design of the knowledge-based innovation framework**

   In stage 2, the main aim was to explore the current practices to manage innovation processes in the manufacturing companies; and the methods/procedures for collecting and storing innovation related knowledge. A case study on "Product Finishing System Design and Specification Process" was carried out at MBAS. In addition to this, another case studies was conducted with CTOOLS – cutting service provider to explore the innovation practices and knowledge storage and utilisation methods. The members of innovation team, managers, directors were interviewed to collect data for the case studies.

3. **Validation of the knowledge-based innovation framework**

   In the final stage, the knowledge-based innovation framework was validated with managers and senior engineers in the participating companies. Their comments and suggestions were utilised in the further refinement of the proposed framework. In addition to this, the research findings were validated through conference papers, poster and presentations to academic community.

3.4.4 Industrial Visits and Observation

Being part of the research team working on the ExtremeFactories project, researcher had opportunities to observe innovation processes at all the participating industrial partners during the three years of the project's lifespan. During this period, the researcher was involved in numerous project meetings both online and offline, industrial visits and workshops. In these events, the researcher interacted frequently with companies' directors, managers, engineers and scientific staff. These informal conversations played a key role in data acquisition regarding their innovation and knowledge management practices and utilising them in the case studies.

3.4.5 Document and Archival Analysis

As one of the objectives of the research is to develop CKR, knowledge management practices were studied at the participant companies. During the interviews and project meetings, information about document storage procedures and practices (including systems currently in use to manage documents) were collected. Participants were asked about the effectiveness of their companies' current knowledge storage and utilisation practices. Researcher also gained access to some of the documents related to past cases for system design and implementation at participating companies. This allowed researcher to judge the effectiveness of current knowledge storage practices and how employees utilise this knowledge in their innovation processes.

3.4.6 Data Analysis

To draw out pattern from concepts and insights about practices applied in manufacturing, both qualitative and quantitative methods were applied to analyse the collected data. For the data collected using the survey approach, frequency tables were calculated to summarise the distribution of answers in the sample. The cross tabulation approach was applied to understand the relationship between different variables as it allows the researcher to compare the relationship between two variables. In contrast to the frequency tables, which summarize information about one variable, cross tabulation generates information about bivariate relationships. The data collected from the case studies were also included into the survey so that the results of the analysis painted a complete picture of the of the events in SMEs. The data from the preliminary questionnaire was analysed using SPSS software.

Knowing the distribution of the answers has helped gain insight to the current innovation and knowledge management practices in manufacturing SMEs as well as the methods and approaches that are more widely used by SMEs. Another insight given by the survey were the areas that needed improvement in the KM processes in SMEs.

3.5 Summary

Innovation and knowledge management is a challenging subject and require a focused research effort. This chapter explained the methods and methodology applied in this research programme for collection and analysis of the data; and outlined the means to achieve the research objectives.

The applied research methodology was designed to uncover current innovation and knowledge management practices in manufacturing SMEs. After a careful review of potential research methodologies, the Triangulation research approach has been selected. The approach is capable of achieving the research aims of creating and evaluating an innovation framework incorporating novel knowledge repository to support innovation processes in manufacturing SMEs. A questionnaire was designed to get a broader view of the Innovation processes in manufacturing SMEs, followed with several case studies to gather the data needed to achieve the objectives stated in Chapter 1.

The next chapter now discusses the research data collected from the industrial survey and case studies to explore current knowledge management and innovation practices in manufacturing SMEs.

CHAPTER 4 - KNOWLEDGE MANAGEMENT AND INNOVATION PRACTICES IN SMES

4.1 Introduction

Chapter 4 examines existing knowledge management and innovation practices within manufacturing SMEs and provide justification for the proposed research by identifying gaps in the knowledge and innovation practices. In order to develop Knowledge-based Innovation Framework and the CKR presented in Chapter 5 it is vital to look at existing practices in manufacturing SMEs and identify and address their advantages and disadvantages.

The chapter starts with review of practices reported by academics and practitioners on Knowledge and Innovation Management. The results of literature findings are compiled to design a preliminary survey which is used to conduct primary research in manufacturing SMEs with a view to validate literature findings and answer research questions listed in Chapter 1. Based on the responses of the survey, the companies are selected for further study of their innovation process using case study approach. The questionnaire results and case studies of selected manufacturing SMEs are described in this chapter.

4.2 Knowledge Management Practices in Manufacturing SMEs

Similar to other management practices, Knowledge Management was developed in large organisations and was later applied on small and medium-sized enterprises (McAdam and Reid, 2001). Therefore, most of literature in this field describes details of Knowledge Management approaches and their implementation at large organisations (McAdam and Reid, 2001). For example, Lloyd (1996) described the Knowledge Management practices of Dow Chemical, an American multinational chemical corporation, and Siemens, which is the largest industrial manufacturing company in Europe. Whereas, the Knowledge Management practices at British Petroleum, Boeing and Anderson Consulting were published by Davenport and Prusack (1998) based on their experience while working in these organisations. Brown and Duguid (2002) cited studies of Orr on Xerox and Cole's on Hewlett-Packard. Nonaka and Takeuchi (1995) also focused their research on large firms e.g. Canon, Honda, Matsushita and other multinational organisations in Japan. In contrast, this research programme is investigating practices of knowledge management particularly for knowledge applied in Innovation process in SMEs. Researchers (Egbu et al., 2005; Holm and Poulfelt, 2003; Skyrme, 2002) have already pointed the research gap in the knowledge practices of SMEs in literature.

Although, little has been published on Knowledge Management practices at smaller firms it does not mean that there no such practices exist in SMEs. In fact, the research done by Skyrme (2002) stated that smaller firms do practice the knowledge management in their daily activities without recognising it. In other words, KM practices exist in SMEs without the use of Knowledge Management terminology. Hutchinson and Quintas (2008) have defined these practices as informal KM, in contrast to formal KM that refers to management of policies, plans, structures, initiatives, projects and practices by the concepts of KM. By taking the informal knowledge management approach into account, it can be stated that SMEs do have processes to manage knowledge (Earl and Gault, 2003).

There are a number of challenges that affect the KM practices in SMEs. For example, many smaller firms often have limited resources (Jarillo, 1989), therefore it is very important for them to use their resources wisely as erroneous decisions can have a serious impact on their survival compared to larger organisations. In addition to the limited resource availability, Cerchione et al. (2015) discovered 11 barriers in successful implementation of KM practices. These are "business culture, financial barriers, integration with existing processing, lack of shared language, lack of confidence in benefits, lack of managerial support, lack of staff skills, lack of time and resources, protection of critical information, tacit and non-formalised knowledge, and technological barriers". From these, the protection of critical information and integration with existing processes are stated as the top 2 barriers affecting the implementation of KM practices. A research by Cerchione et al. (2015) on barriers hindering the spread of KM practices in SMEs found that the current Knowledge Management Systems (KMSs) used by majority of SMEs are outdated and expensive to maintain. The common examples of these systems include database, document management system, e-mail, newsletter, data warehouse, social media, wiki, and content management system (Cerchione et al., 2015). For managing knowledge, companies should consider upgrading their systems to new technologies (e.g. cloud computing) which are also less expensive and more user friendly. These new systems also do not require significant human and financial investments (Cerchione et al., 2015). However, the results of a study by Cerchione et al.(2015) were based on data from SMEs operating in high-tech industries and therefore can be applied in similar environment. Their validity has not been tested on SMEs in manufacturing sector which is a focus of this research.

In contrast to larger organisations, small firms have a flat, informal and non-bureaucratic structure; and a free-floating management style (Durst and Edvardsson, 2012). Generally, in small organisations the owner plays a central role (Bridge et al., 2003) and s/he manage the business planning and decision-making processes (Culkin and Smith, 2000). This means s/he is also responsible for determining the value of knowledge management to support the organisation's innovation activities. As firms' day-to-day activities require the owner's close attention s/he often lacks sufficient time for important strategic issues such as knowledge management (Hofer and Charan, 1984). Additionally, the lack of financial resources and expertise required to implement KM practices are other big barriers which force employers to keep the knowledge in their mind and/or some key employees and block the way for a systematic approach for physically storing and sharing knowledge among other members of the organisation (Wong and Aspinwall, 2004). Thus, the researchers believe that knowledge sharing is carried out using informal ways such as corridor conversations (Wong and Aspinwall, 2004) or at organisational social functions e.g. members' birthday parties etc (Durst and Edvardsson, 2012).

Based on the above, it is clear that the small firms face unique KM challenges. Therefore, they need specially tailored KM approaches to meet their needs. However, many researchers tend to apply KM approaches developed for larger firms in SMEs (Susanne and Runar, 2012). This creates the risk for smaller firms to lose their distinct characteristics and capability to act. To address these issues, this research programme has investigated the KM practices in SMEs using the questionnaire and the interview approach. The information collected was then used for the design and development of a knowledge-based innovation framework described in Chapter 5. The results of the questionnaire and interviews are described in section 4.4 and 4.5.

4.3 Innovation Practices in Manufacturing SMEs

Globalisation and tough competition is forcing SMEs to continue to "reinvent" themselves and produce new products and/or services in order to survive and compete. The innovation model, in most of manufacturing companies, is based on a "me too" policy i.e. copying functionalities from competitors, mainly triggered by the invasion of new products in the market or the obligation to abide by new standards and regulations. Copying makes sense as it keeps R&D costs down, shortens the time-to-market and lets at least the management to believe that they are doing well in the new markets. However, plagiarising does not differentiate the product offering, leading to head to head competition, where first comers have the competitive advantage.

By being aware of the importance of innovation, many international organisations have made huge efforts to normalise or standardise the innovation process such as My Starbucks Idea Portal (Starbucks), Bright Ideas (Dell), etc. There are commercial products to capture knowledge and process innovation ideas, such as Siemens' 3i (Ideas, Impulses, and Initiatives) or Chrysler's EBOK (Engineering Book of Knowledge). Most of the systems use heuristic methods to support knowledge capturing. However, there are no tools in the market to effectively collect ideas, needs and knowledge which are adapted for SMEs. Existing tools are either simple – like suggestion systems – or do not provide means to motivate and help people come up with ideas within an Extended Enterprise Context, or they are too elaborate for SMEs. Also, they do not properly support re-use and sharing of knowledge among different experts and players within manufacturing SMEs, and their maintenance requires knowledge-system specialists.

Rowan Gibson (2008), business strategist, argues that the idea of setting up a Suggestion Box whether it's physical or online is simply not enough. However, there is nothing wrong in this approach; indeed, it is the simplest and cost-effective way for idea collection. The main problem with this approach is that when companies institute such activities then the employees submit all the ideas they have. What happens after some time is that people do not have any ideas to submit anymore. Therefore, it is very important to create an environment where the employee can get inspiration to come up with new ideas. It can be concluded that traditional enterprises, but specially manufacturing SMEs, do still need to face deep organisation and cultural changes to adapt themselves to any such improvement processes.

To overcome the above-mentioned issue, various innovation management frameworks have been developed and implemented. However, they are mainly designed to meet the requirement of large organisations. SMEs still face the challenge of selecting affordable frameworks which meet their special needs including strategies, tools, and methods, and then successfully implementing such frameworks (Nada et al., 2010). The research investigating the relationship of multiple aspects of innovation capability and firm performance by Saunila (2014) suggested that the performance can be improved by developing innovation capability in SMEs. The research found that innovation capability impacts financial performance more than operation performance whereas ideation and organising structures have positive relationship with both financial and operational performance (Saunila, 2014). However, the research found negative relationship between a participatory leadership culture and financial performance (Saunila, 2014).

In a research by Nada et al. (2012), SMEs' innovation capability relies on seven components: Innovation Strategy, Innovation Process, Leadership and Culture, Collaboration and Partnering, Business and Technology, Innovative organisation, and Learning. In their work, Nada et al. (2012) discovered that SMEs' lack of well-defined innovation strategy and process. While a research by Terziovski (2010) on 600 Australian SMEs found that innovation strategy and formal structure in SMEs are key drivers of their performance, the research suggested that the SMEs can improve their performance by mirroring large manufacturing firms and utilising innovation culture in a strategic and structured manner (Narayanan, 2001 as cited by Terziovski, 2010). SMEs need to start the process of assessing their business components to understand possible opportunities and define their innovation goals and objectives. They should develop a set of structured processes to manage their innovation activities from idea generation, prioritisation through to implementation. In regards with leadership and culture, *"SMEs are still in the basic level of building the* *foundation for a more innovative climate while some SMEs counteracted a cultural tendency toward the status quo"* (Nada et al., 2012). To foster innovation culture, SMEs need to acknowledge innovation as a top priority and initiate new programs to promote learning in their organisations. Collaboration and partnering with industrial companies and governmental organisations is considered key to gain competitive advantage. However, SMEs' collaborations with academia and their customers were found ineffective and not adequate (Nada et al., 2012). Their means of collaboration are still unstructured. The collaboration usually takes place via face-to-face meetings and on an ad-hoc informal basis. This could be the reason that much of the knowledge gets lost (Nada et al., 2012). Therefore, there is a need for SMEs to look for collaboration tools such as wiki, social network and group support systems; to identify gaps and formally include practical know-how in their daily innovation activities, as a source of ideas and a means to enable innovation.

This research also looked at factors that hinder the innovation process in SMEs. Most commonly stated causes of failure are: lack of time and resources, poor allocation of teams and resources, poor goal definition, poor action alignment, poor feedback of results, poor performance monitoring (Dolley and O'Sullivan, 2003; Ziarati et al., 2013). In addition to this, the researchers have looked at sector specific barriers. Through a survey of SMEs in the mechanical and electrical engineering sector in Netherland, Keizer et al. (2002) found that the lack of research and development investments, low state funding, ambiguous structure to manage the innovation process are the key factors that affect the ability to innovate. Whereas, work carried out by Mulligan (2002) on supplier SMEs found that poor collaboration between customers and suppliers and inaccurate interpretation of customer requirements are the major causes of innovation failure. Some of the researchers stated that the attitudes of top managers to taking risk, employee resistance towards innovation, lack of technological expertise and lack of technological education in SMEs are the key barriers in the area of skills (Piatier, 1984; Bessant and Rush, 1992).

The following section commences the presentation of the questionnaire results and elaborates upon the findings of the survey carried out to evaluate the current innovation and knowledge management practices in manufacturing SMEs.

4.4 Questionnaire Results

As described in Chapter 3, the Questionnaire approach is used to collect data from companies to a) Understand innovation processes in manufacturing companies - how they come up with new ideas, methods and tools used in idea generations etc; b) Investigate how companies apply knowledge related to principles and practices in the innovation process and methods used to store such knowledge.

The analysis and findings of this questionnaire are described in the following sub-sections. The questionnaire was initially distributed to 2 companies on a pilot basis and later involved more companies (28 involved later, a total of 30). The intention was to use the questionnaire to gather the necessary data to respond to the key research questions raised at the start of this research programme.

The SPSS software package has been used for statistical analysis of collected data. The results are presented in following sections in form of tables, bar charts and pie charts.

4.4.1 Knowledge Management and SMEs

A number of questions were designed to understand views associated with knowledge management in manufacturing SMEs. In one of the questions, the participants were asked about their perception about Knowledge Management in their organisation. The responses received are presented in the table below.

Table 4.1 - Knowledge Management and Manufacturing SMEs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never heard of it	4	13.3	13.3	13.3
	Something they are doing but not under same name	15	50.0	50.0	63.3
	It is a strategic part of the business	11	36.7	36.7	100.0
	Total	30	100.0	100.0	

The results have shown that Knowledge Management is an important part of manufacturing SMEs. The majority of companies (86.7% of total responses) have some sort of practices for Knowledge Management although they are not using the exact terminology, whereas 36.7% of companies have it as a strategic part of the business.

4.4.2 Existing Policies and Procedures of Knowledge Management

The main objective of this section was to examine participants' view about KM practices in their organisations and whether they keep them in written form. The results of these questions are presented in the tables below.

Table 4.2 - Policies and Procedures of Knowledge Management in Manufacturing SMEs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	17	56.7	56.7	56.7
	No	12	40.0	40.0	96.7
	Don't Know	1	3.3	3.3	100.0
	Total	30	100.0	100.0	

For KM strategy or initiative to be successful, it is important to have KM policy or strategy available in written form. The survey results have shown that 40% of participating SMEs don’t have their knowledge Management policy/strategy in written form. The absence of clearly defined KM strategy can cause shortage or overload of knowledge. Therefore, it is important for the proposed framework to have a KM strategy.

In the next questions, the participants were asked about status of KM policies and procedures in their organisation.

Table 4.3 - Status of KM Policies and Procedures in Manufacturing SMEs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	It is very important, relevant and latest	8	26.7	26.7	26.7
	It is very important, relevant but not updated regularly	17	56.7	56.7	83.3
	It is just trivial, a part of formalities and of no use.	5	16.7	16.7	100.0
	Total	30	100.0	100.0	

The results have shown that majority of SMEs don't update their KM policies or procedures regularly. The definite reason behind this is unknown. However, this could be due to having KM strategy not in written form. Additionally, the limited resources might be a reason.

4.4.3 Tools in Use for Information and Knowledge Storage

The existing literature on KM is mainly focus on specific KM systems and do not provide insights into existing tools in use for knowledge storage within manufacturing SMEs (Cerchione et al., 2016). The researchers (Cerchione et al., 2016) stated that there is a clear need for more thorough investigation of KM tools employed by SMEs. This research question addresses this gap and provides insight onto existing tools used by SMEs.

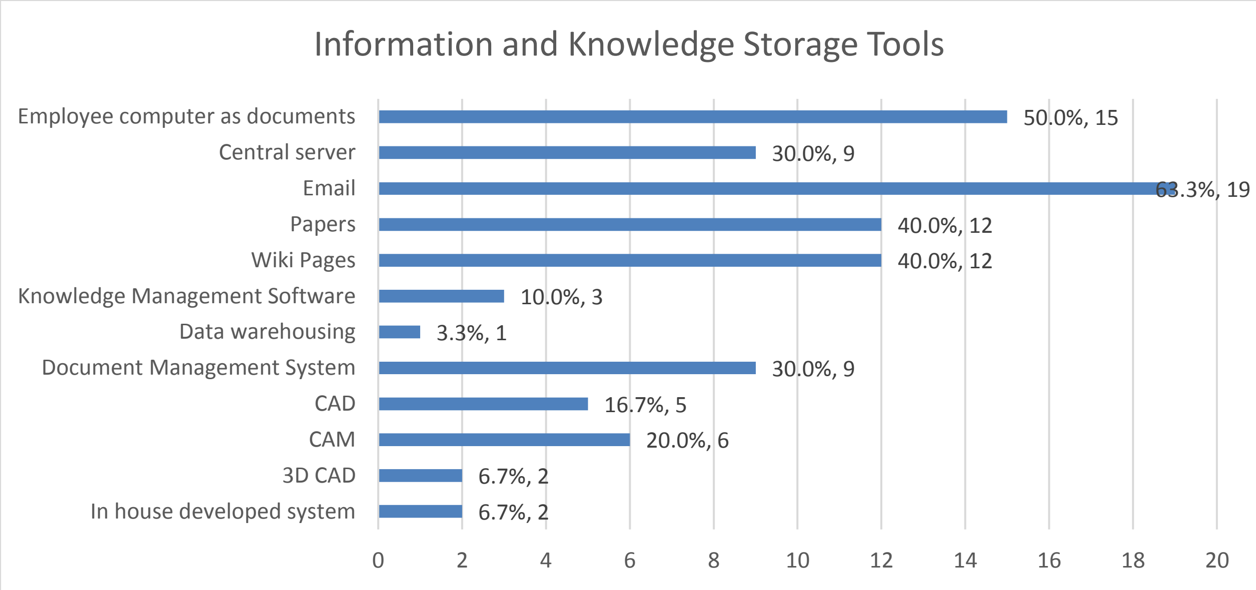

Figure 4.1 - Tools for Information and Knowledge Storage within Manufacturing SMEs

Table 4.4 - Tools for Information and Knowledge Storage within Manufacturing SMEs

Information and Knowledge Storage Tools	**Responses**		**Percent of Cases**
	N	**Percent**	
Employee computer as documents	15	15.8%	50%
Central Server	9	9.5%	30%
Email	19	20%	63.3%
Papers	12	12.6%	40%
Wiki Pages	12	12.6%	40%
Knowledge Management Software	3	3.2%	10%
Data warehousing	1	1.1%	3.3%
Document Management System	9	9.5%	30%
CAD	5	5.3%	16.7%
CAM	6	6.3%	20%
3D CAD	2	2.1%	6.7%
In house developed system	2	2.1%	6.7%
Total	95	100%	316.7%

The above table has shown the varieties of tools that are being used for information and knowledge storage within manufacturing SMEs. Although the majority of the participating SMEs stated that KM is an important strategic part of their business, they are still using old fashioned approaches such as Email, Paper, and Employee computers for storage; or continue to use them with other advanced approaches of knowledge storage. The most commonly used tool reported is Email which is being used by 63.3% of total participating SMEs, followed by Employee computers which are used as main storage media.

Before the rise of computer and information technologies, the information was stored on Papers. Although, keeping important information and knowledge on Papers is not an ideal approach as it can get lost or can get damage. Despite this fact, 40% of participants reported Papers as one of storage medium. This not only poses the risk for information to get lost but also makes it hard to discover the required information in the future.

4.4.4 Ideal Tool for Knowledge Storage in SMEs

For a new system or approach to be successful, it is important that the users are interested in it. Therefore, the specific question was designed to identify SMEs' preference on type of tool they would prefer to use for information and knowledge storage. The majority of SMEs shown interest in connected data technologies, where 70% stated they would prefer to use it over other approaches. This finding has highlighted an important requirement that the proposed system have to address.

Table 4.5 - Ideal Tool for Knowledge Storage in SMEs

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Connected Data Technologies	21	70.0	70.0	70.0
	Internet applications like Wiki Page	4	13.3	13.3	83.3
	Document Management System	4	13.3	13.3	96.7
	Other	1	3.3	3.3	100.0
	Total	30	100.0	100.0	

4.4.5 Factors Hampering Knowledge Storage and Utilisation

The objective of this section was to examine the factors that hamper knowledge storage and utilisation in manufacturing SMEs and compare it ones reported in the literature. The existing publications have stated lack of technical knowhow, poor sharing of knowledge, and mismatch between SMEs requirements and existing system as key reasons that hinders the successful implementation of knowledge storage and utilisation practices (Cerchione et al., 2016; Esposito and Evangelista, 2016; Milosz and Milosz, 2010; Nunes et al., 2006; and Desouza and Awazu, 2006). To validate these findings, a specific question on factor hindering knowledge storage and utilisation practices was added into the questionnaire. The responses to this question are presented in the table below:

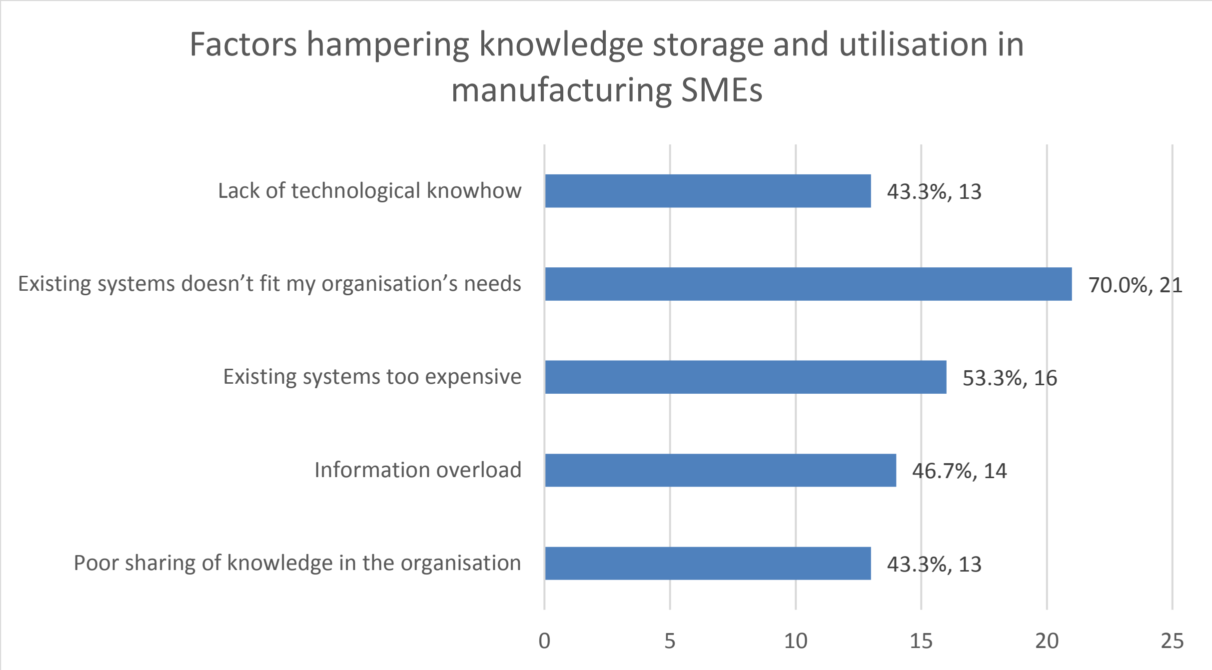

Figure 4.2 - Factors Hampering Knowledge Storage and Utilisation

Table 4.6 - Factors Hampering Knowledge Storage and

Factors hampering Knowledge Storage and Utilisation	**Responses**		**Percent of Cases**
	N	**Percent**	
Lack of technological knowhow	13	16.9%	43.3%
Existing systems doesn't fit my organisation's needs	21	27.3%	70.0%
Existing systems too expensive	16	20.8%	53.3%
Information overload	14	18.2%	46.7%
Poor sharing of knowledge in the organisation	13	16.9%	43.3%
Total	77	100.0%	256.7%

It is clear from the chart that the key factors that hamper knowledge storage and utilisation are in line with what has been reported in the literature. The most important finding of this research is that 70% of SMEs have stated that existing systems do not match with their requirements. This finding has again justified the need of the proposed research programme and highlighted the area that needs further research.

4.4.6 Information and Knowledge Sources used in the Innovation Processes

The main aim of this research study, as defined in Chapter 1, is to examine and evaluate design of knowledge repository to support innovation processes in the manufacturing SMEs. To achieve this aim and to support the design of knowledge repository, it was important to identify information and knowledge sources which are being used in the innovation processes within manufacturing SMEs. To this end, the participants were asked to report sources that they utilise in their innovation processes. The results of this question are shown in the chart below:

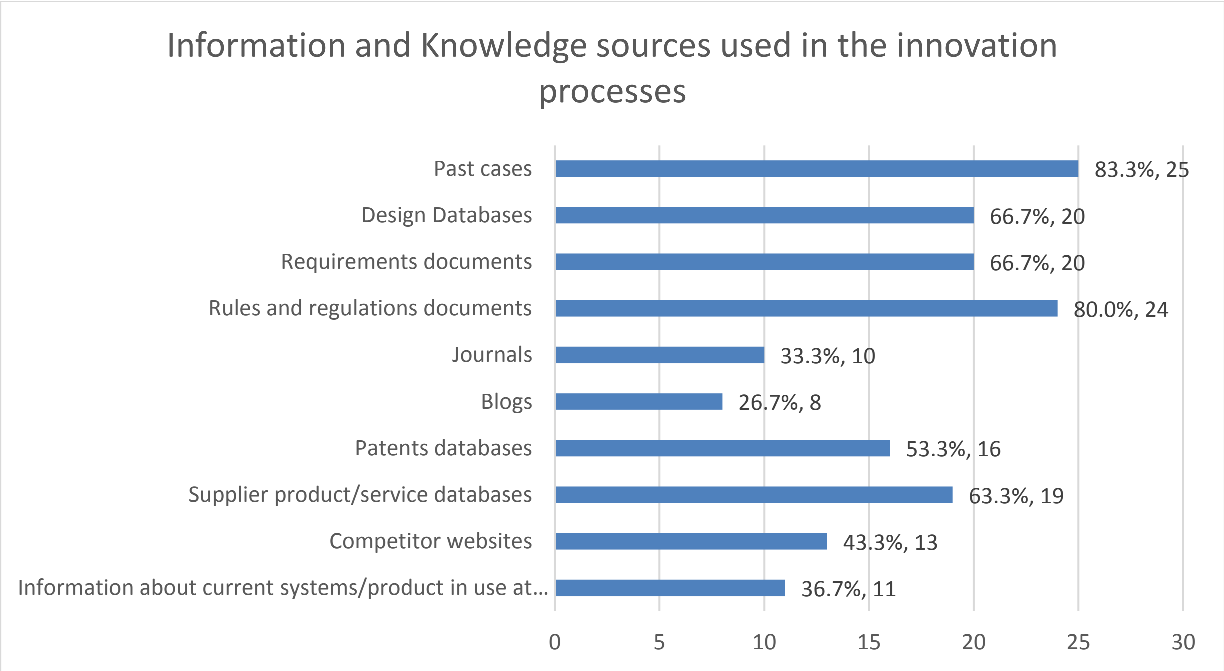

Figure 4.3 - Information and Knowledge Sources used in the Innovation Processes

Table 4.7 - Information and Knowledge Sources used in the Innovation Processes

Information and Knowledge sources used in the innovation processes	Responses		Percent of Cases
	N	Percent	
Past cases	25	15.1%	83.3%
Design Databases	20	12.0%	66.7%
Requirements documents	20	12.0%	66.7%
Rules and regulations documents	24	14.5%	80.0%
Journals	10	6.0%	33.3%
Blogs	8	4.8%	26.7%
Patents databases	16	9.6%	53.3%
Supplier product/service databases	19	11.4%	63.3%
Competitor websites	13	7.8%	43.3%
Information about current systems/product in use at customer's organisation	11	6.6%	36.7%
Total	166	100.0%	553.3%

The chart above has shown that the different sources are used by companies in the innovation processes. There are several factors that affect the selection of these sources: business type, business size, innovation category (i.e. product innovation, processes innovation, service innovation) and nature of innovation process (i.e. collaborative process involving other businesses, closed process involving members of organisation only). Therefore, the proposed knowledge repository has to be designed in such a way that it can address the above mentioned disparities in the innovation processes of SMEs within manufacturing sector.

From experience, the author was aware that SMEs use different data formats when storing innovation knowledge. In order to validate this, the participants were asked to state the data format of information and knowledge sources. The results of this question are shown in the chart below.

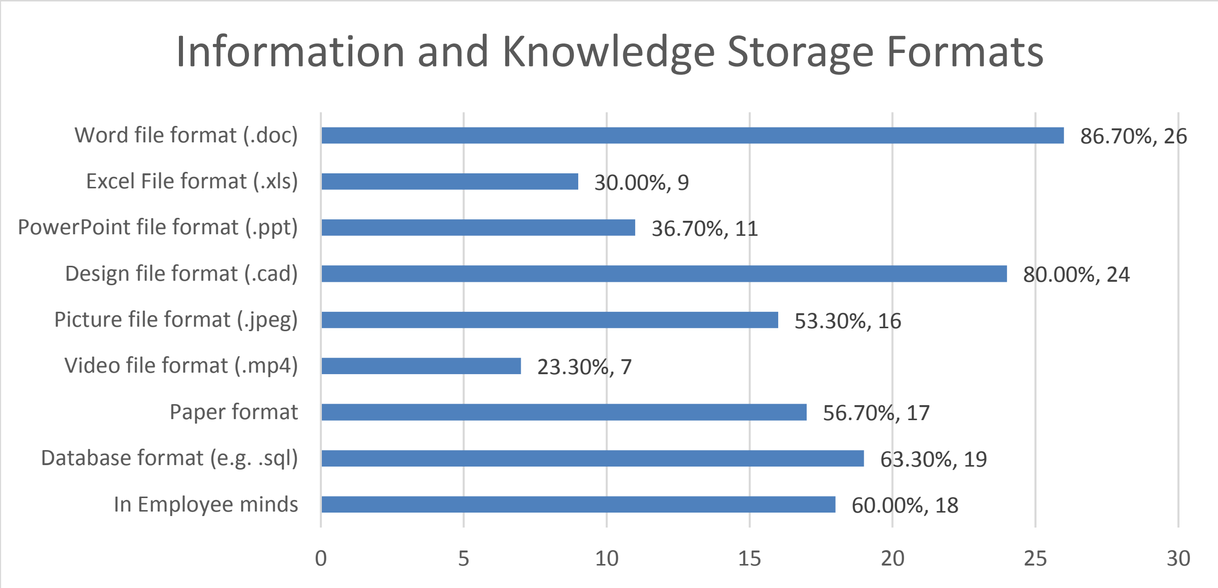

Figure 4.4 - Information and Knowledge Storage Formats

Table 4.8 - Information and Knowledge Storage Formats

Information and Knowledge Storage Formats?	**Responses**		**Percent of Cases**
	N	**Percent**	
Word file format (.doc)	26	17.7%	86.7%
Excel File format (.xls)	9	6.1%	30.0%
PowerPoint file format (.ppt)	11	7.5%	36.7%
Design file format (.cad)	24	16.3%	80.0%
Picture file format (.jpeg)	16	10.9%	53.3%
Video file format (.mp4)	7	4.8%	23.3%
Paper format	17	11.6%	56.7%
Database format (e.g. .sql)	19	12.9%	63.3%
In Employee minds	18	12.2%	60.0%
Total	147	100.0%	490.0%

The above chart clearly shows that Innovation knowledge is stored in different formats within manufacturing SMEs. This disparity in formats makes it difficult to recognise how the information and/or knowledge stored in database (i.e. sql format) relates to information and/or knowledge stored as a word document. This is again an important issue that the proposed knowledge repository has to address. The intended repository has to provide a mechanism so these relationships among knowledge sources become visible.

4.4.7 Drawbacks of Existing Practices

This section discussed the drawbacks of existing knowledge retrieval practices. The participants were asked to state the issues that they face when retrieving/accessing required information and knowledge for innovation activities.

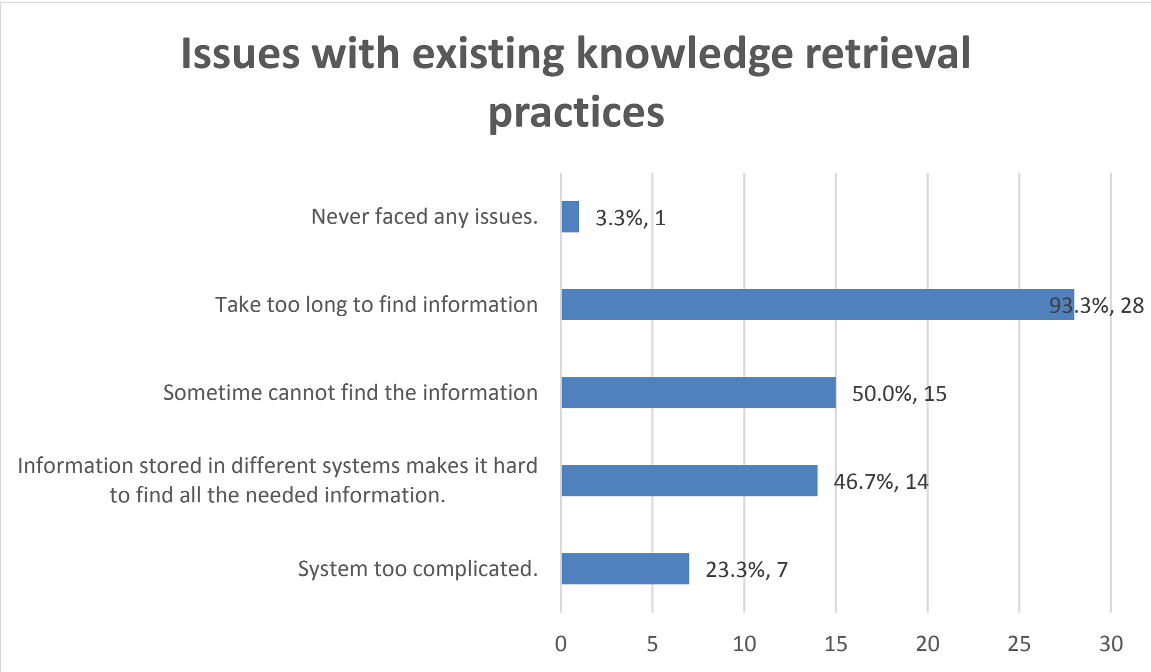

Figure 4.5 - Issues with Existing Knowledge Retrieval Practices

Table 4.9 - Issues with Existing Knowledge Retrieval Practices

Issues with existing knowledge retrieval practices.	Responses		Percent of Cases
	N	**Percent**	
Never faced any issues.	1	1.5%	3.3%
Take too long to find information	28	43.1%	93.3%
Sometime cannot find the information	15	23.1%	50.0%
Information stored in different systems makes it hard to find all the needed information.	14	21.5%	46.7%
System too complicated.	7	10.8%	23.3%
Total	65	100.0%	216.7%

Over 93% participants reported that it took them too long to retrieve the required information from the knowledge sources, while half of them mentioned the possibility of never finding the information. One of the possible reasons for such high percentage could be the traditional knowledge storage practices, which are still in place in many SMEs. It is noted that the majority of companies are still using Papers and Employees' computers to store important information and knowledge, therefore, the chances of information to get lost is very high. Moreover, it becomes more difficult to find a piece of information after the employee who stored that information leaves the organisation.

In addition to the above mentioned factors, the participants stated disparity in information and knowledge storage formats is another major weakness of the existing practices.

4.4.8 Barriers of Knowledge Storage and Sharing Strategy Implementation

The main objective of this section is to examine barriers that hinder the effective implementation of knowledge storage and sharing strategy within manufacturing SMEs. To achieve this objective, the participants were asked to state the obstacles that they faced for effective implementation of knowledge storage and sharing strategy in their organisation. The responses are presented in the table below.

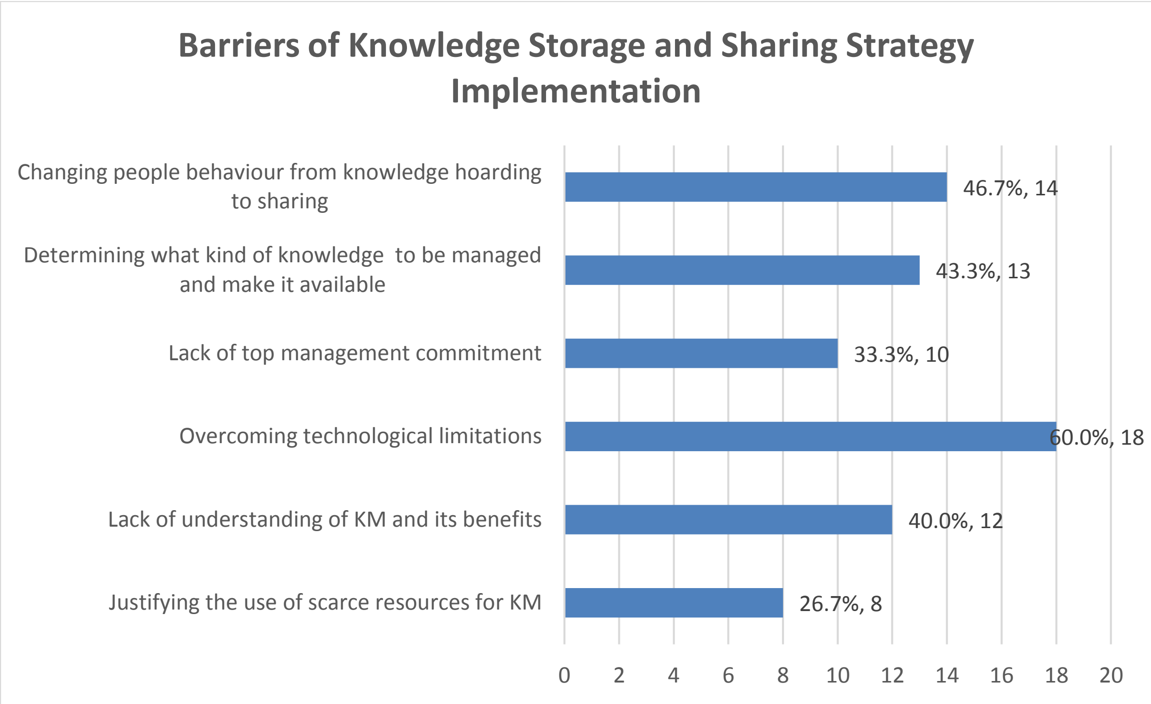

Figure 4.6 - Barriers of Knowledge Storage and Sharing Strategy Implementation

Table 4.10 - Barriers of Knowledge Storage and Sharing Strategy Implementation

Barriers of Knowledge Storage and Sharing Strategy Implementation	Responses		Percent of Cases
	N	Percent	
Changing people behaviour from knowledge hoarding to sharing	14	18.7%	46.7%
Determining what kind of knowledge to be managed and make it available	13	17.3%	43.3%
Lack of top management commitment	10	13.3%	33.3%
Overcoming technological limitations	18	24.0%	60.0%
Lack of understanding of KM and its benefits	12	16.0%	40.0%
Justifying the use of scarce resources for KM	8	10.7%	26.7%
Total	75	100.0%	250%

As it is clear from the table above, overcoming technological limitations and lack of sharing attitude are the biggest barriers that hamper effective implementation of knowledge storage and sharing strategy within manufacturing SMEs. In addition to this, the lack of understanding what should be managed and its benefits are found to be another key obstacles. Whereas, over 33% participants stated that the lack of top management commitment is a core reason behind the failure of KM strategy.

4.4.9 Use of Central Knowledge Repository to Support Innovation Processes

The aim of this section was to gather participants' views on the use of the CKR to support innovation processes. To achieve this objective, the possible responses were arranged in scale of 5 choices namely: Strongly Disagree, Disagree, Neither Agree Nor Disagree, Agree, Strongly Agree. The high percentage of participant supported the idea of using the CKR to support the innovation processes. The results of given responses are presented below.

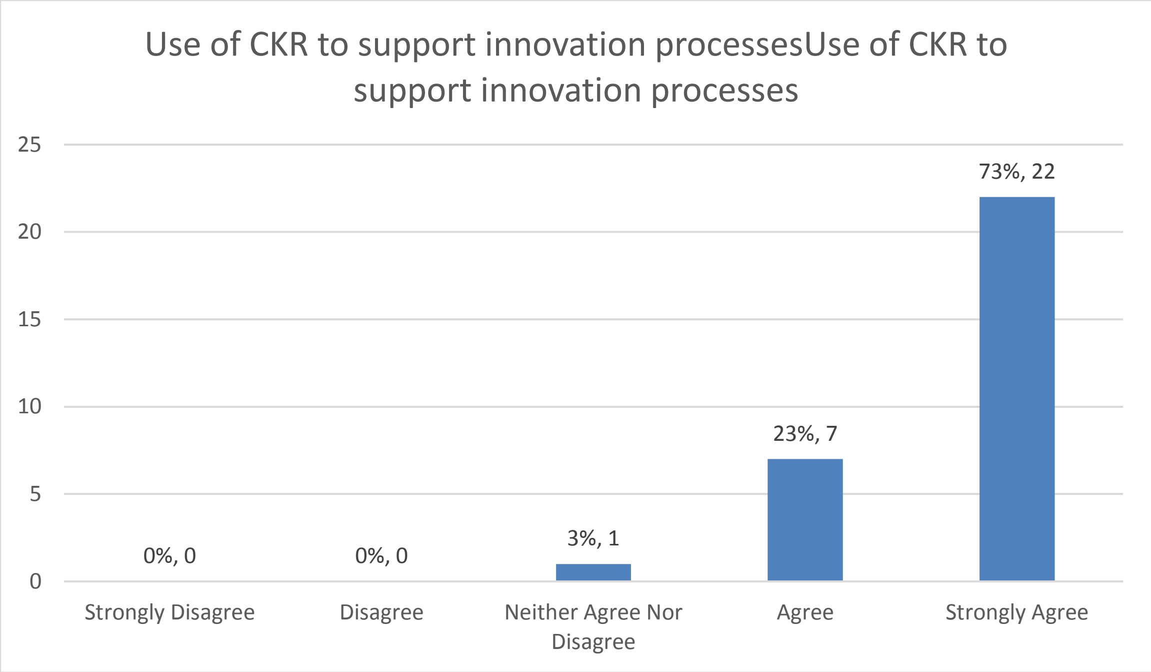

Figure 4.7 - Use of CKR to Support Innovation Processes

Table 4.11 - Use of CKR to Support Innovation Processes

Use of CKR to support innovation processes		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Neither Agree Nor Disagree	1	3.3	3.3	3.3
	Agree	7	23.3	23.3	26.7
	Strongly Agree	22	73.3	73.3	100.0
	Total	30	100.0	100.0	

4.4.10 Ideal Place to Implement KM Strategy

The objective of this section was to identify participants' views on ideal place/level to implement KM strategy in their organisation. The respondents were asked to choose from four options namely: Company-wide, Department Level, Process Level, At all levels. The results are presented in the table below:

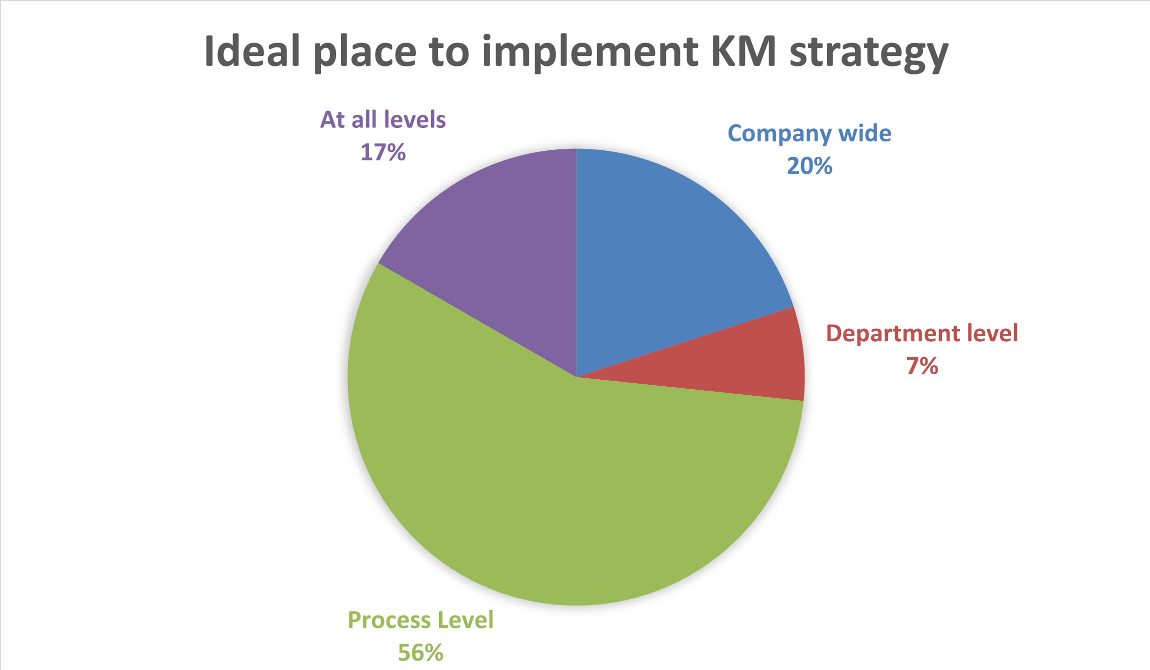

Figure 4.8 - Ideal Place to Implement KM Strategy

Table 4.12 - Ideal Place to Implement KM Strategy

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Company wide	6	20.0	20.0	20.0
	Department level	2	6.7	6.7	26.7
	Process Level	17	56.7	56.7	83.3
	At all levels	5	16.7	16.7	100.0
	Total	30	100.0	100.0	

The majority of the participants stated that the KM strategy should be implemented at Process level. Many researchers and practitioners in KM field have also presented similar views in the literature (Massingham and Holaibi, 2017; Bitkowska, 2016; Marjanovic and Freeze, 2012; Maier and Remus, 2002). As the main aim of this research study is to support innovation processes in SMEs, therefore it makes sense for proposed framework to link KM strategy with Innovation strategy of the organisation. Thus, the organisation will only store what adds value and will avoid wastage of limited resources on storing unwanted information and knowledge.

4.5 Case Studies

As a part of this research programme, case studies of manufacturing SMEs companies are carried out. This study has applied the Explanatory approach. The key objectives of this study were to explore current practices to manage innovation processes in the manufacturing companies; methods/procedures for collecting and storing innovation related knowledge; tools used in coming up with new ideas for improvement or new products/services/processes introduction.

4.5.1 Mb Air Systems – Case Study

4.5.1.1 Description of the Company

In December 2002 the Motherwell Bridge Group completed the management buyout of the business and assets of Motherwell Bridge Air Systems Limited, founded in 1973, and thus Mb Air Systems (MBAS) limited came to be. With almost half a century experience and a broad variety of clients, the company operations specialise in the fields of power tools, compressed air, material handling (industrial lifting), pneumatics and product finishing systems.

MBAS provides an ample variety of products and services, like Maintenance Solutions, Winches and Hoists, Air Compressors, Filter Receiver, Compressed Air Treatment, Product Finishing, Pneumatics, Power Tools, Motors and Starters. MBAS is focused on producing intricate engineering services to industry, primarily managing air compressor solutions, but also supplies capital equipment taking advantage of its international network of suppliers, being ISO9001 certified for these subjects. It operates from 4 locations in the UK (Wishaw, Aberdeen, Seaham, and Fareham).

4.5.1.2 Innovation Management Practice at MBAS

There are several innovation processes at MBAS. "Product Finishing System Design and Specification Process" has been selected for this study as it is closely matched with the research objectives. The process starts with the customer enquiry. Depending on the size and complexity of the enquiry, the contract team is established to design, specify, quote, out-source, manage and review the potential contract. The team may include the Regional Board Director, the Sales Director, the Sales Manager Product Finishing Systems, the Product Finishing Specialist, the Operations Manager and Business Support functions depending on the project type and level of complexity.

This activity occurs upon customer request and each project is different from another; and the final solutions are all different. Therefore, the length of time and frequency of this process varies. In general, the projects could take 8 to 12 months. The main communication tools used during this activity are phone, email, and Skype.

How the process works?

The process starts with the Condition Monitoring activity. The engineering team monitors the client’s existing system using state-of-the-art data acquisition equipment for one week. It collects information to develop an accurate picture of how the current client's system truly operates. During this activity, the team carry out several interviews with the client to discover unspecified needs. At the end of this activity, the information collected by the monitoring tool is analysed by the engineering team. During the analysis process, the team refers to previous similar cases to come up with new solutions (Ideas).

As an output of this activity, a detailed report presenting a clear picture of how the current air system operates and proposing ways to improve system performance is developed. It contains recommended improvements, equipment performance specifications, control configuration and an implementation schedule. This information is used to calculate and configure the most suitable system design matching requirements to technical product data whilst ensuring that legislative and safety requirements are satisfied. Finally, the report proposes several solutions with financial justifications that meet customers' return-on investment criteria.

All proposals are presented to the client. The client decides as per his investment ability and length of time required for the return on investment. MBAS engineering team then starts the implementation process. The process comes to an end when the validation of the implemented solution is completed successfully, and the documents are recorded. Some of the documents are retained in the AESSOP system.

4.5.1.3 Knowledge Management Practices at MBAS

The company heavily depends on knowledge to develop customer-tailored solutions to meet the specific requirements of its customers. This knowledge includes analysis reports of current situation, identified unspecified requirements, similar past cases and technical product information such as "Air Compressor – 10 Year life cycle cost Analysis" chart. In order to acquire such knowledge, MBAS' engineering team performs several data collection and analysis activities. The very first activity is Energy Audits. A special system is set up at the client's location, which captures the important information about Energy consumption. Series of meetings are arranged with the customer to acquire more information on business practices. The structured interview and brainstorming methods are applied to identify unspecified needs. MBAS' engineering team then analyses the energy audit reports and study the customer requirements. MBAS has a repository of past projects which are stored in a secured computer. However, no structured approach or method is used to store these documents. These past project documents related to similar previous cases are also referred during brainstorming sessions to come up with new ideas. The company has "Air Compressor – 10 Year life cycle cost Analysis" chart which is developed by MBAS, to provide different solutions ranging from low cost to more expensive but more efficient solutions. The chart shows calculations of electricity consumption with and without the Air Compressors. It also shows how their product(s)/solution(s) will save money over the 10 years' time period.

Company has a well-defined approach to manage this process. It is known as "Continual Improvement" approach. It has total of 8 phases as shown in the figure below:

Figure 4.9 - MBAS Continual Improvement Approach

The very first phase/activity is to **investigate** the existing system to become aware of customer needs and make the customer aware of MBAS. The next phase is to **understand** whether the customer needs are within business scope, with the aim to identify areas for continual improvement. During the **communication** phase, the engineering team arrange several meetings and brainstorming sessions with the client as well as internally with the MBAS team to identify unspecified needs. Once the System Design and Specifications are defined, the **competence assessment** is performed to verify availability of internal and Supplier resources to satisfy needs.

Based on the outcomes of previous steps, a detailed report proposing several solutions tailored for customer unique requirements is produced. This report is used to **train** the customer about available solutions and their long-term benefits. This activity result in **learning** customer views on presented solutions and making **improvements** in the future proposals. The company uses the AESSOP system to **record** some of the documents for future reuse.

In current knowledge management practices, the biggest challenge for the organisation is to access the existing information and knowledge assets which are available in different formats and at different locations (i.e. employees computers, AESSOP system etc.). The disparity in information and knowledge formats makes it difficult to understand the relationships between information and knowledge sources. For example, there is no way for employees to realize how the information stored in AESSOP is related to past cases stored in a word format. One has to go through all the documents to find the relationship and get access to the full knowledge chain. This results in a lot of time being wasted in searching for the knowledge necessary instead of the development of actual innovation.

4.5.2 Charles Robinson Cutting Tools Ltd – Case Study

4.5.2.1 Description of the Company

Charles Robinson Cutting Tools Ltd (CTOOLS) is a SME, established in 1980, operating in the manufacturing sector, and is a tool manufacturer for industry, and provides cutting services for customers. Cutting Tools apply cutting systems and tools of the highest quality to create cutting equipment for their clients. The company specialises in the use of brand new cutting blades that stay sharp, precision dies and punches, and utilises the finest carbide tools in the production of cutting equipment. Cutting Tools have also made an investment in the latest computer assisted design (CAD) and computer assisted manufacturing (CAM) equipment. One of the company's goals is to update their operations to the latest standards and grow. To ensure the company's survival and competitiveness, Cutting Tools have made important innovations in the cutting industry, providing a wide variety of products and services to a niche market for accurate and complex cutting requirements. Cutting Tools is an innovative company, which is constantly attempting to produce new cutting techniques and products. It has several patents on its name for innovative cutting products, such as the rotary creasing process, cutting process plus a novel skin cutting process for making skin shapes for skin grafts in the medical industry.

4.5.2.2 Innovation Management Practices at CTOOLS

The CTOOLS business is all about collaborative working. For example, many packaging products require CTOOLS to source the material from one company, then to cut it for the printing (another company) and ship (another company) to customer (another company). Another example is a recent job making bulletproof vests for Afghanistan. CTOOLS got the materials from many suppliers, formed a multi-layered structure, assembled it, cut it, sent it to a company that heated it to form a composite, then CTOOLS cut out the final shape, and sent it to the customer.

Innovation for CTOOLS is meeting the customer requirements by creating new tool designs or creating new cutting processes or by creating new cutting machinery. The business' most crucial aspect is the creation of novel cutting processes and tools. The company's ability to create unique cutting tools and methods ensures their survival and competitiveness.

So, innovation is extremely important. The innovation objectives in the company are:

- To boost employees engagement in innovation activities by encouraging them to propose new ideas for improvements in existing product or introduction of new ones.
- To improve firms capacity to transform ideas into real products.
- To engage cross functional team members in brainstorming activities to develop new cutting products/processes – this should lead to greater motivation amongst the workforce

- To work more closely with customers and suppliers to generate new products ideas
- To have a managed way of developing new ideas
- To have a systematic approach to store ideas
- To have a good method of developing innovative products

Regarding identification of a problem and problem-solving techniques, the company only concerns itself with design and manufacturing. The problems are presented to it by its customers and through previous experiences, past RTD project involvements and brainstorming applies a variety of problem solving techniques. CTOOLS uses brainstorming primarily based on previous design experience and review of stored design practices and solutions. The company does not record the outcomes of the Brainstorming sessions, missing relevant information for future projects. Normally during this session decisions to solve immediate problems are taken.

4.5.2.3 Knowledge Management Practices at CTOOLS

CTOOLS has a practice of storing previous designs and problems associated with the work carried out for its customers. The company uses third party software for custom made design and storing previous design practices.

Company has a small team composed of people with a specific design and manufacturing expertise. Knowledge areas and skills are identified by the company and applied to each new project presented by its customers. Normally innovation projects are carried out with the company’s staff, not requiring external expertise, just training activities for the operation of new equipment.

4.5.3 General Discussion and Key Findings

The study has provided insights into the type of data/information utilised in the innovation activities; procedures and practices applied in capturing and storing knowledge; tools used in the innovation process to come up with new ideas; and the innovation process map. From the MBAS case study, it can be stated that knowledge is a key ingredient to produce quality ideas to feed into the innovation process. The type of information/knowledge used in the innovation process includes:

- Past similar cases (or Previous System Designs)
- Safety and regulatory requirements (e.g. Supply of Machinery (Safety) Regs, ATEX, HSG 178, CDM)
- Client specifications
- Any identified unspecified needs
- Data-logging and analysis
- Funding sources – in case of MBAS list of funding body for the client to finance new equipment(s)/solution(s)/product(s) from MBAS.
- Market Intelligence information (e.g. Air Compressor – 10 Year life cycle cost Analysis charts)

A repository of the above-mentioned information/knowledge will be an invaluable asset for manufacturing companies to use in their innovation activities for new product(s)/solution(s) introduction. The advantages of integrating repository of such knowledge with innovation systems are infinite. Employees can be provided with an option to go through this information before presenting their ideas. Hence, the employees will be able to self-validate their ideas and check whether their ideas are in-line with concerned principles and practices e.g. Safety and regulatory requirements. This knowledge-based approach to innovation will promote the concept of Learning Organisation where learning will occur not by chance but will be a part of daily activities.

4.6 Summary

This chapter has fulfilled the 1st, 2nd and 3rd objectives proposed in Chapter 1 and served to validate the research methods and methodology employed. The key concepts studied within this chapter have been derived from the literature as well as from the results of primary research carried out using the questionnaire and case study approaches. It has provided an insight into current practices applied for innovation and knowledge management, tools in use and how innovation and knowledge management is currently occurring within manufacturing SMEs. This chapter has made an important contribution to the existing knowledge by discovering that the concept of the 'Business owner' driving innovation alone doesn't apply to the manufacturing SMEs. An individual could be the sole initiator of the idea but all members of organisation, both internal and external, work together to drive the innovation in manufacturing SMEs.

Literature review has shown a lack of research in the context of Innovation and Knowledge Management in SMEs. The existing methods and approaches were initially developed in and for large organisations and were later applied on SMEs. This creates the risk for smaller firms to lose their distinct characteristics and capability to act. Small firms face unique challenges such as lack of financial resources and expertise required to implement KM and innovation practices, therefore they need specially tailored KM approaches to meet their needs. To address this, this research programme has investigated the KM practices in SMEs using the questionnaire and case study approaches. The information collected has been used for the design and development of the Knowledge-based Innovation framework described in Chapter 5.

CHAPTER 5 - PROPOSED KNOWLEDGE BASED INNOVATION FRAMEWORK

5.1 Introduction

This chapter discusses a new approach to address the issues identified in Chapter 2 and Chapter 4 and propose a novel Knowledge-based Innovation Framework based on CKR to support the innovation processes in manufacturing SMEs. As mentioned in Chapter 2 , efforts have been made to support companies, especially larger ones, to manage their innovation processes. Various innovation models and platforms have been developed to support the design and development of products and services. However, researchers have paid less attention to systematise the innovation processes and activities of SMEs, besides the fact that these companies make the larger contribution in the economic growth of the country. It has also been noted that the innovation processes differ with respect to the firms' characteristics such as size, industry, revenue etc. Therefore, there is a significant difference in innovation processes of larger companies versus SMEs. To adapt innovation processes for SMEs, it is important to address their special characteristics such as No Product Manager/Limited Resources for Market Analysis, Smaller R&D projects, Less Defined Company Strategy, Small Development Groups (Huang et al., 2002). Apart from these characteristics, researchers haves also highlighted several obstacles for innovation management in smaller firms (Mcadam et al., 2004; Scozzi et al., 2005; Madrid-Guijarro et al., 2009; Demirbas et al., 2011).

This chapter presents a novel framework to support manufacturing SMEs in their innovation processes. The proposed framework is composed of innovation processes, knowledge management process, and CKR. It is a response to the problems of identifying ideas and how they should be prioritised and selected more effectively and efficiently. It also creates an environment of good ideas to be generated such as developing a learning organisation within the enterprise. Irrespective of the effectiveness and efficiency of generating and prioritising ideas there is a dedicated repository to store information about SMEs' goals, objectives, principles and practices in an electronic format. The idea presenter will have an option to go through this repository (knowledge source) before s/he present her/his idea. Thus, ideas which are not in-line with the company's goals, or not well thought through, can be discarded in the initial stage. The architecture of the proposed innovation platform is described in detail in section 5.4.

5.2 Proposed Innovation Theme

The theme of the proposed framework has been developed to facilitate the introduction of new ideas and turning them into product, process or service through the interaction between four vital elements of innovation management which are innovation process, innovation team, innovation knowledge and innovation tools within a combined innovation environment as shown in Figure 5.1. All four elements are essential requirements to bring innovation in a company.

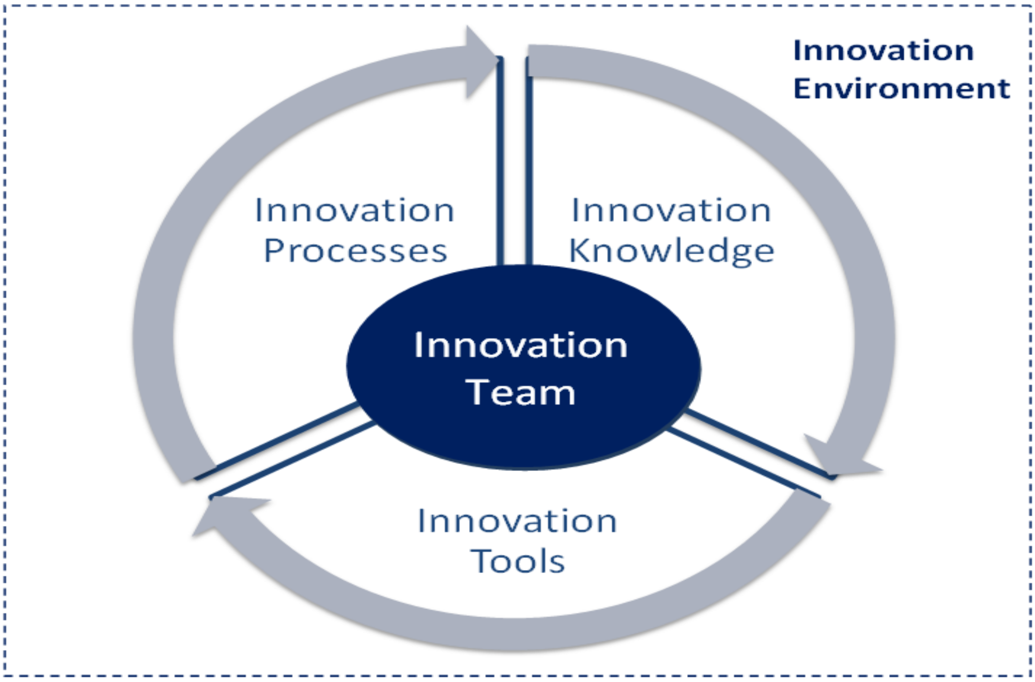

Figure 5.1 - Proposed Elements of Innovation Environment

The Innovation Team plays a vital role in the proposed framework. It assures the interaction between innovation processes, innovation knowledge and tools and uses them to come up with an innovation product, process or service ideas. Knowledge is also a key element that has great impact on the success or failure of an innovation. Good knowledge about the company's innovation goals and objectives can lead the innovation team to the right directions and results in the generation of innovative solutions that are directly in-line with the company's goals and objectives. Additionally, the team should have extensive knowledge of the problem area before proposing an idea or solution. Such knowledge should be structured intelligently to achieve quality results. Proposed innovation knowledge will be structured in such a way that innovation team can embrace several advantages.

5.3 Innovation Process Map

The general view about innovation management in SMEs is that the owner is the sole innovator in the organisation. However, this research has found that Innovation is a collaborative effort which involves all members of extended organisations such as suppliers, employees, customers etc. In one of the case studies in this research, the company director described how the company is using the knowledge of its suppliers to decide on the type of material to be used in their products. This has helped the company to save money and time by avoiding a trial and run process.

Based on information collected from surveys, interviews and case studies, this research has proposed the innovation process map as presented in Figure 5.2.

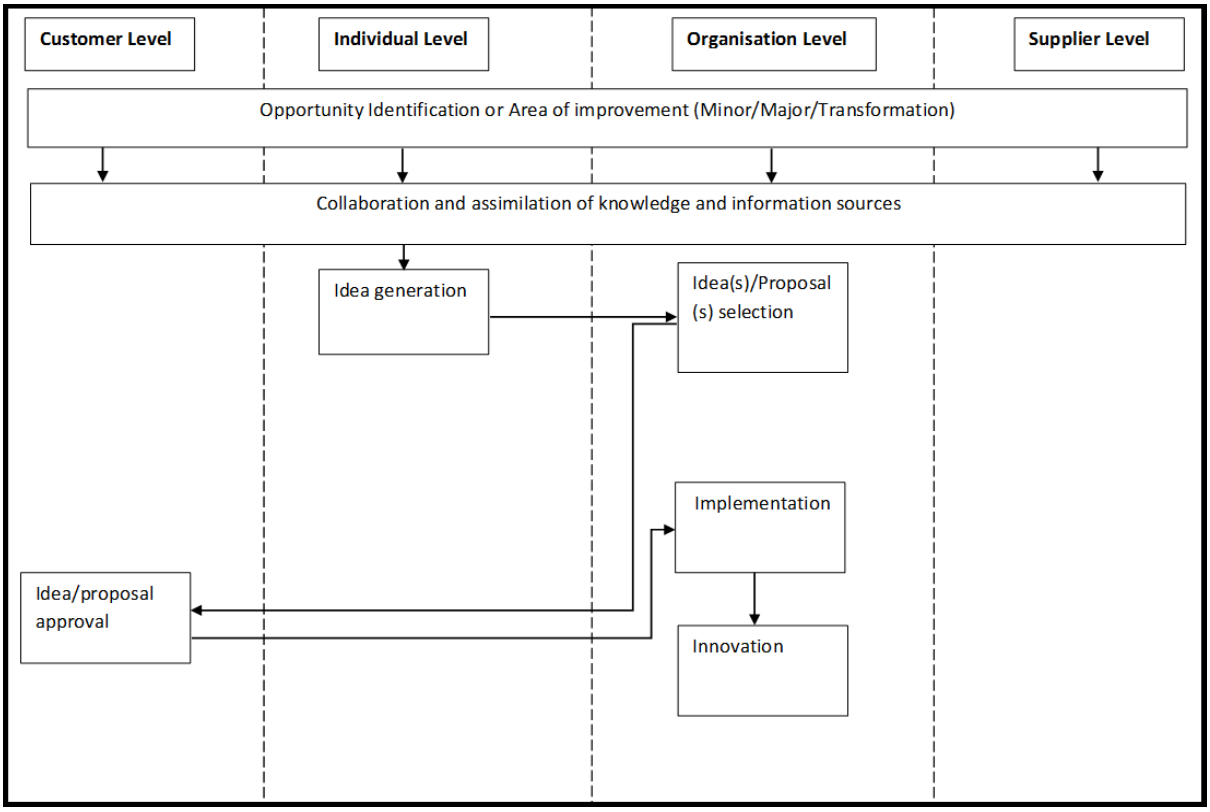

Figure 5.2 - Innovation Process Map

The proposed innovation process map has four key actors involved in the innovation process i.e. customer, individual (owner, employees, consultants, expert etc), organisation and supplier. The process starts with opportunity identification or area of improvement (minor/major/transformation). This could either come from a customer as a problem in their companies that they want to address or a supplier who has come up with new product. In any case, the innovation team collaborates and assimilates the required knowledge from the available information sources. This research has found that creating the initial ideas lie with the individual. The idea can only progress to next phase if it has approval from the organisation. In build-to-order type manufacturing SMEs, the proposal is presented to the customer for his approval. This is the final stage which decides whether to implement the innovative idea or not. Once approved, the implementation process starts and ends with the innovation. This could either be a product, a service or a new/improved process.

5.4 ExtremeFactories Innovation Methodology

The proposed research framework is an extension of ExtremeFactories' Innovation methodology which is developed by the ExtremeFactories project consortium with support from European Commission's research funding awarded under Seventh Framework Programme. ExtremeFactories Innovation methodology has formulated the innovation process into five phases: Preparation, Inception, Prioritisation, Implementation and Follow-Up. The process has been depicted into the picture below.

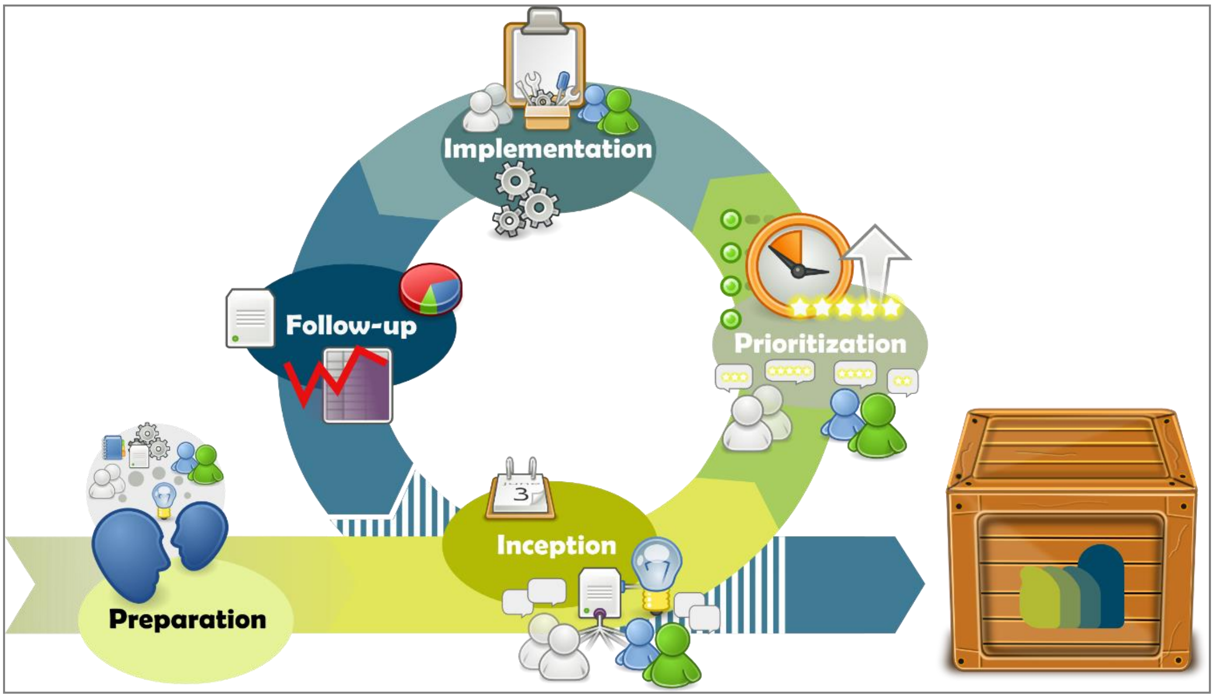

Figure 5.3 - ExtremeFactories Innovation Process

The innovation process starts with Preparation Phase where the participating company sets the Innovation Context, Objectives, roles and responsibilities etc. All this information is composed as a part of Innovation Strategic Plan document. The next phase, Inception, focuses on the process of ideation. In this phase, the company set up the innovation campaign and open it to its employees, supplier, customers and other members of the organisation. These actors then provide their ideas and comments on ideas submitted by other members. These ideas are then moved to third phase of the innovation process called Prioritisation. This phase involves careful assessments of ideas using number of assessment methods to check their market value and company capability to implement them. This process is composed of a number of predefined Innovation Sprints to be negotiated among decision makers. The innovation process is then moved to Implementation Phase. At this stage, the idea becomes the project. The project is composed of number of tasks and sub-tasks. It can also be broken down into sub-project depending on the complexity of the project. The Implementation Phase involves turning concept design into final design and developing a final product. The innovation process ends at Follow-Up Phase. This phase involves keeping track of all the events/activities that happened in the previous phases and evaluating the innovation process. The detailed description of each phase of the ExtremeFactories Innovation Process has been described in the ExtremeFactories Innovation Methodology Workbook available on ExtremeFactories website[4].

The proposed innovation framework has fully subscribed the ExtremeFactories Innovation process and extended it by adding knowledge management process. In addition, the framework is proposing to have knowledge checkpoint where the users will be presented with further information about their idea and provided with an option to go through that information. The proposed framework is described in detail in the next section.

5.5 Knowledge-Based Innovation Framework

The proposed Knowledge-Based Innovation Framework is an extended version of the innovation framework for manufacturing SMEs proposed by the EU funded ExtremeFactories project. The ExtremeFactories project has proposed a new methodology based on agile practices, for enhancing the innovation management process in manufacturing SMEs. The proposed methodology has been assessed and validated in 7 industrial SMEs from different business cases which include: Management Improvement, Product Improvement/Creation and Process Improvement/Creation.

The given framework, as shown in Figure 5.4, proposed an integrated knowledge management process based on the organisation's innovation strategy. It provides a workflow support capability that captures and retrieves knowledge required for innovation processes, i.e., within the context in which it is created and used. Both Innovation and knowledge

[4] http://www.extremefactories.eu/download/D2.1.2_EFF_MethodologyWorkbook_v2.0.pdf Accessed on 30-12-2018

management processes are derived from the organisation's Innovation and Knowledge Management Strategy which is part of a company's overall business strategy. In the heart of framework is the Central Knowledge Repository that stores all the information generated/captured by the innovation and knowledge management processes through learning organisation and quality circle practice.

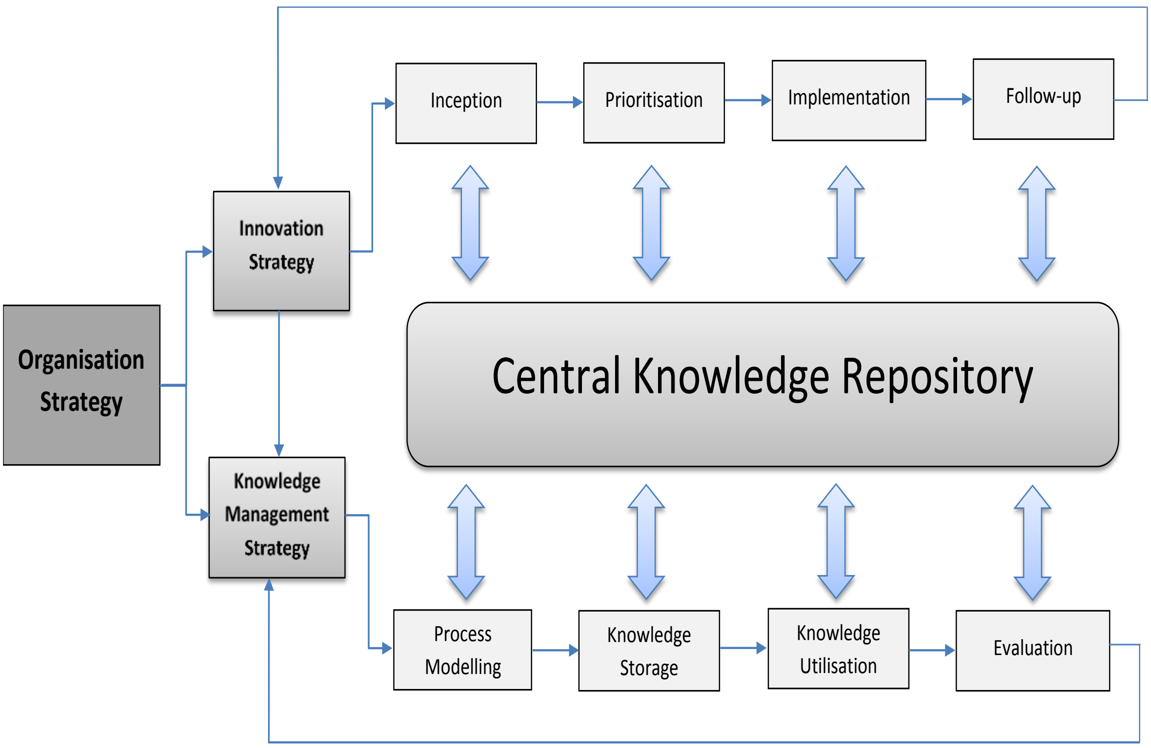

Figure 5.4 - Knowledge-Based Innovation Framework

The framework provides flexibility to the companies to set their own innovation goals and objectives, use appropriate idea generation tools to support in idea generation activities. All innovative ideas can then be assessed using various assessment tools. It is also important to measure the value of an idea; and the company's capability to successfully implement it. The winning idea will then move further to the next phase which is the development phase. Once the idea goes through the implementation phase by passing all validation tests, it will then be launched in the market. The last module of the framework allows companies to document the success stories of innovation. It could be used as a check point when implementing a similar innovative idea/project in future.

The following section provides detailed information about each individual module of the framework.

5.5.1 Innovation Management Process

The proposed innovation framework is composed of four modules considering the complexity of innovation process. Each module involves a number of activities and processes to be carried out by the innovation team. A detailed functionality of each module is described below.

5.5.1.1 Preparation – Definition of Innovation Strategy

Innovation is often treated as a risky game. Therefore, companies always hesitate to spend resources to do something innovative. On top of that manufacturing SMEs have limited budget for innovation activities and it is important to use it wisely and avoid risks at the early stage of innovation process. The preparation phase addresses all these issues by setting the innovation context so companies can build an innovation culture and adapt to changes/innovation and view innovation as an opportunity not a threat/risk.

The preparation phase proposes that companies should clearly define the following innovation governance responsibilities:

- Setting up innovation goals and objectives
- Defining responsibilities of each player of the innovation team
- Arranging budget and resources for innovation activities and process.
- Deciding criteria for measuring innovation

- Rewards to promote engagement in innovation activities
- Setting up roles for managing innovation process

By means of setting the above innovation governance responsibilities, companies can build an innovation friendly environment to foster the innovation. It is argued that if the innovation process is managed properly and risks are identified and mitigated at the initial stage then the result could be much more fruitful.

Every company has its own innovation goals and objectives. It is important that all the ideas proposed by the members of extended enterprises are strictly in-line with these goals and objectives. Otherwise, there will be huge waste of resources and money which will be misused for the assessment and evaluation of irrelevant ideas.

5.5.1.2 Inception

The Inception phase can be defined as an engine of innovation process. At this stage, employees and extended members of the enterprise are encouraged to submit as many ideas as possible. This stage is also known as fuzzy front end of innovation, where the things are not very clear. Therefore, it is very important that companies should identify clearly what is the problem that they are seeking a solution/idea for and what are the possible constraints and requirements that an ideal idea should meet. Additionally, there should be a way to search for existing solutions. The proposed module answers all these questions with the following procedures:

- Client's meeting to gather requirements
- Requirements analysis and problem formulation
- Defining goals, objectives, requirements and constraints from the previous two points
- Searching existing available solutions or ideas

- Propose a new idea(s)/solution(s)

It has been noted that knowledge of a specific domain results in quality idea generation. In order to address this issue, the Ideation module is embedded with the self-assessment tool that enables the innovator to go through information related to the problem's domain. For example, if an employee has a design idea, the module offers an option for an individual to go through design principles and practices before s/he submits her/his idea. In this way, ideas which are not aligned to the company's goals or not well thought through, can be discarded in the initial stage. A complete flow chart of the proposed approach is shown in Figure 5.5.

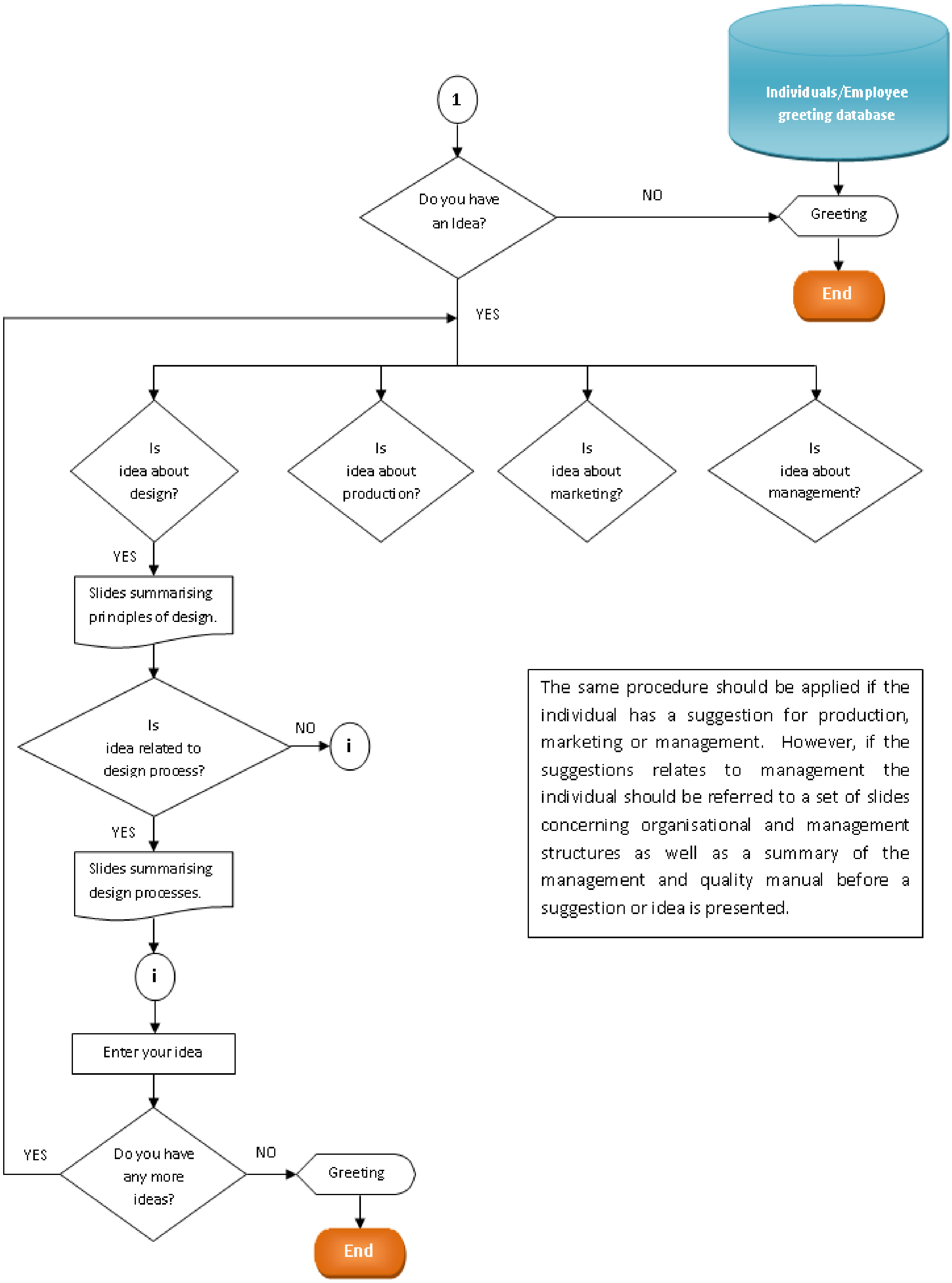

Figure 5.5 - Principles and Processes Knowledge Check Point

The similar approaches have been proposed for management, senior managers and Stakeholder. The flow charts demonstrating both approaches are included in Appendix D and Appendix E. This is a new addition to existing Inception process of ExtremeFactories' innovation process.

The Ideation module proposes numerous creative thinking tools to generate new ideas and share them with other team members. The selection of creativity tools depends on the problem's nature, the total amount of resources and time available. Some techniques can be applied in a small group of people while some may require a larger group to participate. The proposed Ideation module is shown Figure 5.6.

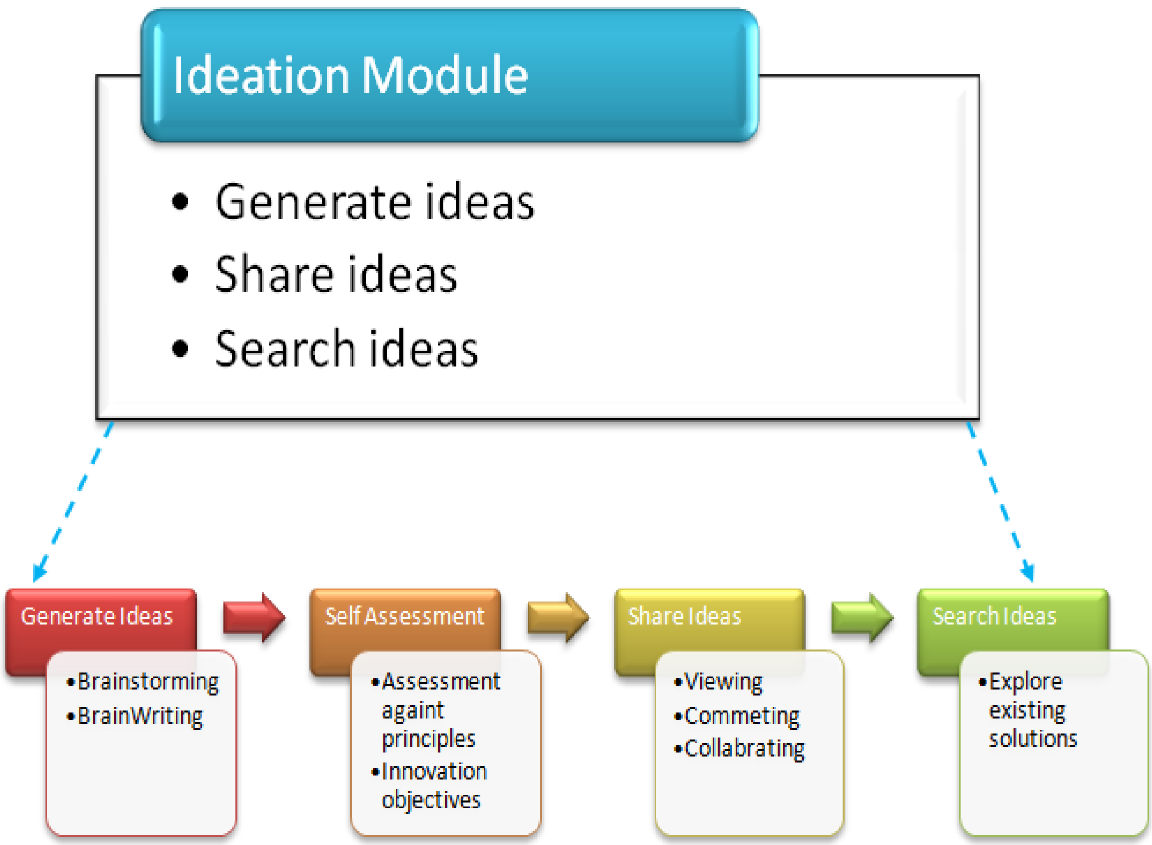

Figure 5.6 - Ideation Procedures and Tools

5.5.1.3 Prioritisation

As it is clear from the name, this module is to deal with the evaluation of submitted ideas. The strength of this module is its ability to determine what ideas will be the next blockbusters and which will be a flop. In some markets, every 9 out of 10 new products are a failure, but one can minimise the risk and maximise the chances of success by applying an effective assessment method/process.

The right selection of the assessment team is a key to the success of this phase. Developers or members of the quality circle team may not always know which ideas are good and which product idea will bring large revenue in the company. Therefore, it is suggested to compose a cross-functional team, which can measure market potential, the company's capability to develop an idea, provide cost and time estimation to implement the idea and so forth.

A three-step approach for idea evaluation has been proposed. In the first step, the idea will be measured against a set of criteria to check the idea value (i.e. market potential) and the company capability (i.e. does the company have enough resources, funds and time) to develop/manufacture the proposed idea. These assessments also include an estimation of the idea's development in cost and time. Thereafter, in the second step the idea proposer is asked to present his/her idea to the other members. It will give other people the chance to provide feedback and also get inspired to propose new ideas. Finally, the rating methods will be applied to rate all the submitted ideas. The proposed procedure and tools for idea assessment are shown in Figure 5.7.

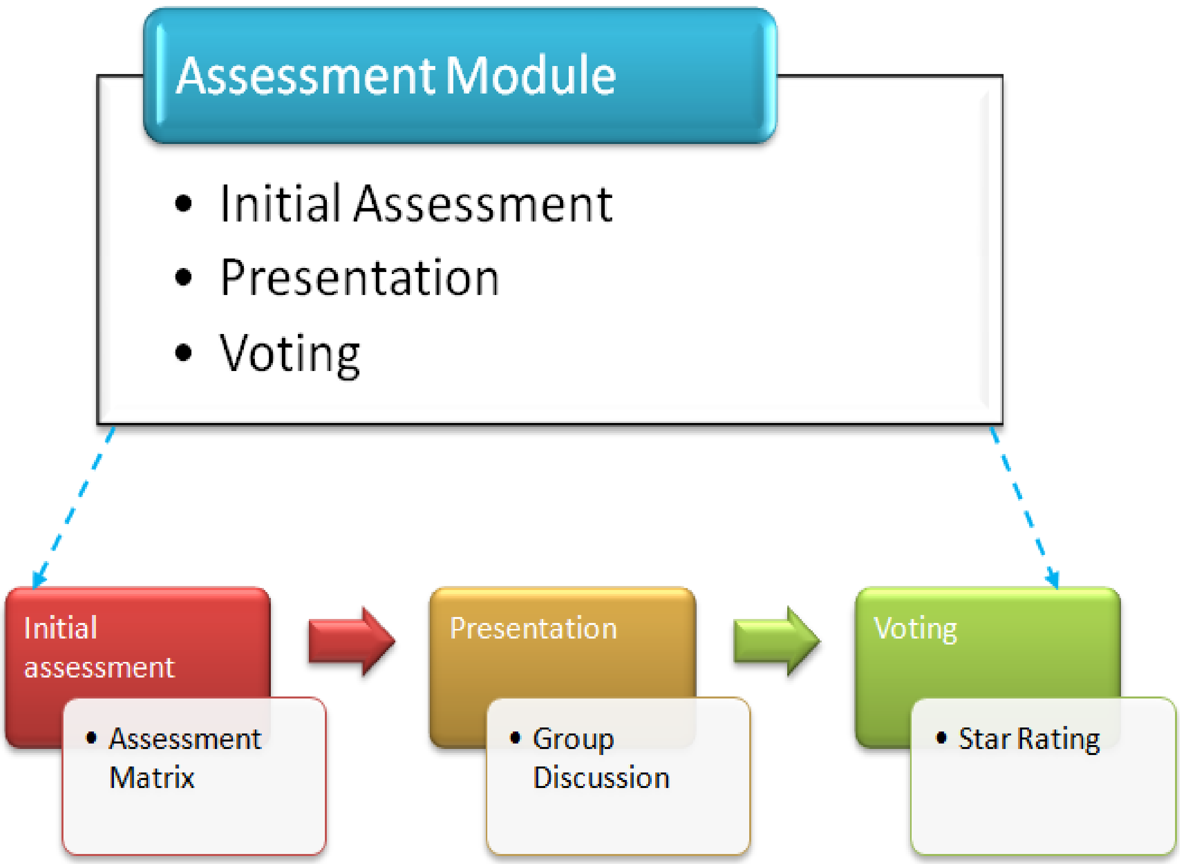

Figure 5.7 - Idea Assessment Procedure and Tools

This is last step of the innovation process before the idea is sent off for production or manufacturing. Therefore, it is very important that only the right ideas pass through this stage to avoid any financial loss.

This module proposes the concept of merging similar ideas together into one idea. The final idea will be presented to management for final decision. At this stage, the company would have already measured the idea's value; and the company's capability to implement it using an assessment matrix and would have estimation about how much time and money is required for implementing it. Additionally, the idea already would have been presented to a group of selected people to get their consent and votes using star rating. The selection module will analyse all the data and will present it to board members in a user friendly way which will make it easier for them to understand. This structured information will help management to make an informed decision. The diagram of idea selection module is presented in Figure 5.8.

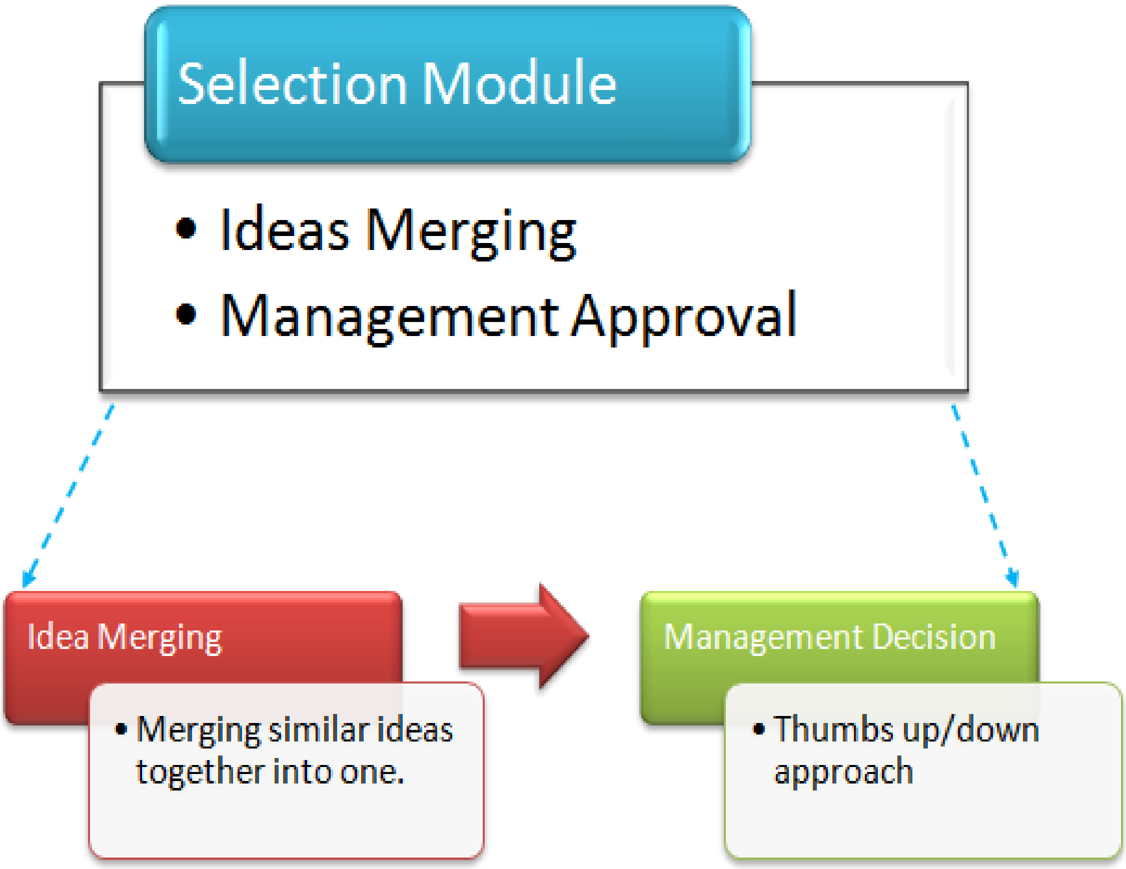

Figure 5.8 - Idea Selection Procedure and Tools

5.5.1.4 Implementation

This is the phase when an innovative idea become project after getting accepted by the board members. By this time, companies would not only know the market potential of the proposed ideas but would have documented all the possible risks and have an action plan to mitigate and deal with them.

The implementation module involves the following activities and procedures:

- Setting up a team which will look after the development phase including testing and validation
- Development of short and precise in-roads towards the successful completion of the innovation idea's goal (like the “sprints” commonly used in SCRUM)
- Keep an active eye on the market and stay ready to update the requirements to fulfil market demand
- Critically validate all the client(s)/customer(s) requirements and make sure they are met.
- Regular testing of the completed work until all the test criteria are satisfied.
- Trial Run to give final checks before actually launching the idea to the world.

This phase also deals with preparing for the big day, the launching day, including setting up a launch date, and time; and place where it should be revealed for first time ever. Depending on the nature of the innovative idea, the activities and procedures may vary. For example, when brining innovation in management practices or production process in the company, the company may not have to think about certain activities which are required in case of launching a new product idea. In general, this module will involve the following procedures:

- Development of a marketing plan (its depends on nature of the idea)
- Setting up the launch date and time
- Choose the right place to launch the idea
- Launch of idea to the world (Its depends on nature of the idea)

5.5.1.5 Follow Up

This is the last, but a very important phase of the innovation process. It requires two key activities to take place. First, it keeps record of all the activities and events from the Ideation phase to the launch. Second, it involves reporting of the market performance of an idea.

Keeping record of all events and activities is an important part of the process. Organisations can use this information as a learning material to know what actions and processes led to the success or failure of an idea. Hence, the users and the platform itself build up a knowledge base of innovation success stories/case-studies. These success stories can be referred in the future when implementing similar innovative ideas.

Depending on the nature of an idea, there are number of indicators that can be applied to measure the success of innovation e.g. revenue versus operational costs, increase in sales or percentage of energy saved or waste reduced etc.

All this knowledge will be formed as a story as shown in Figure 5.9, which could be re-used or consulted at any point in time the in future. The conceptual diagram of this phase is shown in Figure 5.9.

Figure 5.9 - Success Stories Database

5.5.2 Knowledge Management Process

This section describes the knowledge management process to identify and manage the knowledge sources that could be used to support the innovation activities in manufacturing SMEs. In academic literature, knowledge is stated as a critical factor to sustain competitive advantage (Nonaka and Takeuchi, 1995; Teece, 1996; Wiig, 1997; Davenport and Prusak, 1998), and for its effective implementation it is essential to have a solid and deliberate plan in place right from the start (Davenport and Prusak, 1998). In addition, it requires that the management support long-term strategic view, unremitting commitment and employee enthusiasm over a long period to gain real and lasting benefits from the KM strategy (Ruikar et al., 2007; Liebowitz, 2008).

Researchers have found differences in the type KM strategies applied by companies (Chourides et al., 2003), but the need for formal KM approach remains. To this end, the research has formalised the KM process into five phases: Knowledge Management Strategy, Knowledge Modelling, Knowledge Storage, Knowledge Utilisation and Evaluation. The KM process is a new addition to ExtremeFactories' innovation methodology. These phases are described in detail in the following sections.

5.5.2.1 Knowledge Management Strategy

This phase is concerned with definition of KM strategy to meet organisational knowledge requirements. For effective implementation of KM process, it is important to align it with organisation's innovation goals and objectives. For example, in manufacturing SMEs, one of the objectives could be to enhance productivity of the engineers to reduce the lead time and increase profit by fast delivery of the product/project. Thus, the corresponding KM strategy can be making information and knowledge sources easily available for the engineers so they can spend time on their innovation activities rather than searching for information.

Researchers (Zack, 1999; Tiwana, 2000) have noted that the differences in companies' culture, structure and organisational objectives reflect their choice for the KM approach. Therefore, the organisations need to consider these factors when defining their KM strategy (Heavin and Adam, 2013). Hansen et al. (1999) also presented similar views and mention that, *"a company's knowledge management strategy should reflect its competitive strategy"*.

The lack of dedicated KM strategy is found to be a key reason for the failure of KM (Chourides et al., 2003). To this end, the proposed framework uses the organisation's innovation strategy as a starting point to define the knowledge management strategy to achieve its strategic goals. The strategy formation includes outlining and aligning KM objectives with innovation objectives, and allocation of necessary resources for KM and employees' training (Chourides et al., 2003). It also covers identification of organisation's needs and requirements, and evaluation of KM strategy (Duffy, 1999; Carlsson, 2001; Pillania, 2008). Thus, the effective KM strategy will enable organisation to realise what they need to know to support and drive innovation.

5.5.2.2 Knowledge Modelling

This phase covers identification and analysis of knowledge-intensive activities with a view to identify information and knowledge sources being used in the innovation process. This phase is closely linked to organisation's KM strategy so the company can focus its KM process to manage knowledge that adds value. In addition, it will help in efficient use of SMEs' limited resources.

The knowledge modelling process is composed of three sub activities:

- Knowledge Identification – the activities for identifying useful sources for knowledge modelling, analysis of skills and competences
- Knowledge Specification – Modelling of knowledge model(s)

- Knowledge Refinement – Validation of knowledge model(s)

The phase starts with knowledge identification activity in which organisation identifies the innovation process to formulate its information and knowledge needs and requirements. Once the process has been identified, the next step is to apply appropriate knowledge engineering methodology to identify the information and knowledge sources used in the selected process. In this research study, the author has applied CommonKADS methodology which is a de facto standard for developing KM applications.

The next step, Knowledge Specification, deals with complete specification of knowledge to build initial domain conceptualisation. This domain-specific conceptualisation is then used as an input to construct domain schema. The last step, Knowledge Refinement, covers verification and validation of identified schema against knowledge requirements. This phase is described in detail in Chapter 6.

5.5.2.3 Knowledge Storage

This stage covers activities related to the storage of information and knowledge identified during second stage of the KM process, in such a way that relationships between different information and knowledge sources become visible. This stage is also referred as a process that deals with the formation of organisational memory by storing knowledge in a physical memory system (Alavi and Leidner, 2001). Walsh and Ungson (1991), define it [organisational memory] as *"stored information from an organisation's history that can be expressed to bear on present decisions"*. In other words, it is about storage of past cases with the view to use them in future projects or support decision making process (Gonzalez and Martins, 2017).

The survey analysis, presented in Chapter 4 has shown that the SMEs uses several information and knowledge resources in their innovation activities and all these resources are stored in difference formats. The disparity in storage formats makes it difficult to understand how these assets relate to each other resulting employee spending huge amount of time in searching for information. A serial entrepreneur and start-up advisor, Hiten Shah, highlighted the extent of this problem on his blog where he stated *"I've spent at least 20 minutes every day trying to find the right documents. 5 days a week, 52 weeks a year, that's over 80 hours a year just looking for documents. Two weeks wasted for each full-time employee"*[5].

To address above mentioned issues, the research has looked at various methods of knowledge representation. A Graph based knowledge storage and utilisation approach is found to be an idle solution to define relationships among information and knowledge sources. Graph database uses graph structure composed of nodes (entities), edges (relationships) and properties to represent and store data. The implementation of graph database has been described in detail in Chapter 7.

5.5.2.4 Knowledge Utilisation

The knowledge utilisation is a most important phase of KM process as only this generates value in the organisation (Durst and Edvardsson, 2012). In addition, the ability to locate and use the stored knowledge is critical for the success of KM process. This phase provide means for utilising knowledge from the repository.

The research has proposed an integration of knowledge checkpoints, as shown in Figure 5.5, before idea submission to provide an opportunity to employees to look at information and knowledge related to their idea (such as principles and practices, past cases, previously submitted similar ideas etc). This will not only avoid irrelevant ideas to get into the system but also enable use of the stored knowledge and promote learning in the organisation. In addition, these incremental steps toward learning can also provide other benefits such as:

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[5] https://www.producthunt.com/upcoming/fyi/messages/so-much-trouble-caused-by-a-single-document accessed on 25/05/2018

- Fewer idea get rejected
- Less supervision needed because of development and improvement in employees' knowledge
- Better management of time
- Transform organisation into a learning organisation.
- Increase in productivity
- Better personnel performance
- Learn faster than competitors
- Reduces the risk of employee leaving due to learning initiatives [Knowledge checkpoints allowing employees to learn new or improve existing knowledge] (Bassi et al., 1996 as cited by Kapp, 1999)

To implement knowledge checkpoint functionality, the information and knowledge have to be stored in such a way that it could be understood by the computer system without human interaction. The academic literature and survey results have shown that SMEs refers to numerous knowledge sources in their innovation activities. Therefore, it is important that the knowledge tool has a capability to realise the relationships between these sources and provide full access to the knowledge chain.

5.5.2.5 Knowledge Evaluation

Knowledge evaluation phase allows the organisation to assess the quality and quality of stored information and knowledge against its knowledge requirements defined in Phase 1 – Knowledge Management Strategy. The ultimate goal of this phase is to identify new and/or changing needs of the company and feed them back to the knowledge strategy. It ensures that the organisation never faces scarcity of information and knowledge required for the innovation processes, and the KM system can effectively address the KM challenges to maximised the benefits for the organisation.

Most of the existing KM frameworks, whether they are prescriptive or descriptive as defined by Holsappele and Joshi (1999), have proposed a cycle process (Hajiheydari et al., 2012) with feedback loop back to the start of KM process. The proposed KM process has followed these approaches and added a feedback loop back to KM strategy that re-evaluates organisational KM needs and requirements by considering factors such as the company's innovation strategy, KM strategy, new or changing requirements/practices etc. It defines the evaluation criteria and provides means for analysis and monitoring of the knowledge management process with a view to measure success and promote learning.

5.5.3 Central Knowledge Repository

The Central Knowledge Repository is an essential element of the proposed framework. It holds all the information and knowledge required in the innovation process. This knowledge can be presented to innovators before they submit their ideas. It would stop the submission of ideas which are technically not correct by taking into consideration the principles and practices of a specific domain. Knowledge about existing innovation projects and activities can also be re-utilised to learn the best practices and procedures that lead to the success of an idea.

In addition to the management of information and knowledge of knowledge-intensive tasks in innovation processes, the research proposes the development of information and knowledge that is found to be important for the innovation processes. The proposed CKR is composed of several sub repositories. These are discussed below:

5.5.3.1 Repository of Principles and Practices (RPP)

As mentioned earlier, it is important that a firm keeps an electronic copy of its principles and practices. RPP proposes the concept of presenting slides of principles and practices before an individual presents his/her idea. This information will enable self-assessment and validation of an idea before it's actually presented onto the innovation system. On the same time, it implements the concept of learning organisation by providing an opportunity for employees to learn about best practices. A conceptual model of RPP is shown in Figure 5.10.

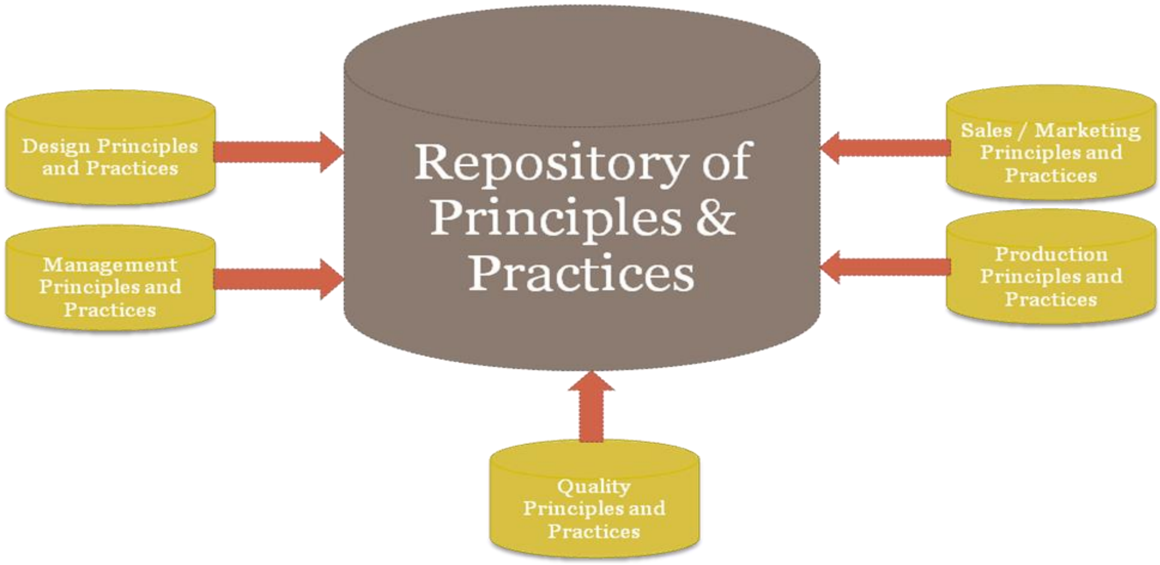

Figure 5.10 - Repository of Principles and Practices

5.5.3.2 Innovation Repository (IR)

Innovation Repository stores knowledge about company's innovation ideas, current and past innovation projects, innovation processes and activities and so forth. Furthermore, detailed reports about past success stories will be stored in IR that could be referred for future selection, evaluation and implementation of similar ideas. The knowledge about procedures and practices which led to the success of an idea can be studied and reused. A proposed structure of IP is shown in Figure 5.11.

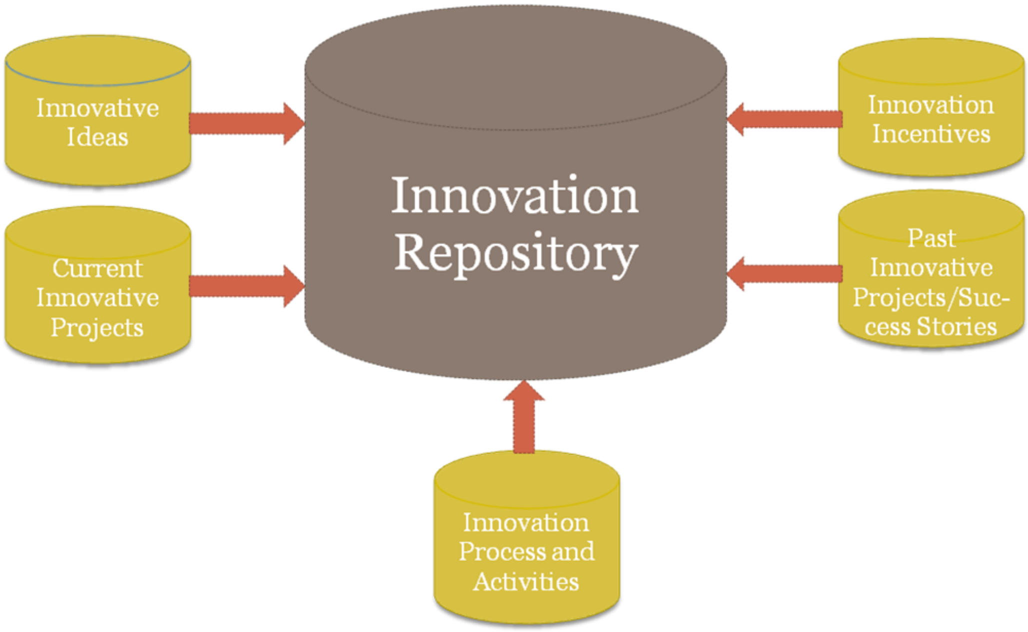

Figure 5.11 - Innovation Repository

5.5.3.3 Funding Repository (FR)

It has been noted that many innovation projects dies due to the lack of funding to support the development of the project. To address this issue, a special repository has been proposed to keep records of all the national and international funding opportunities. A mechanism will be developed to match these funding with an idea. Apart from this, other initiative such as government support schemes, information about angel investor will also be stored in FR. It would enable SMEs with limited resources to take their idea further from concept to reality.

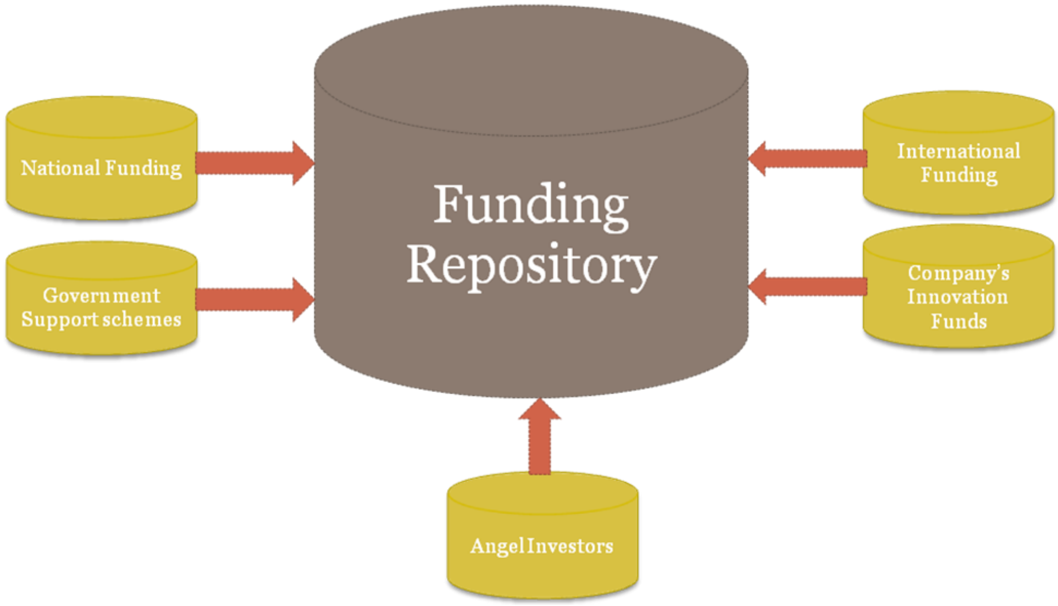

Figure 5.12 - Funding Repository

5.5.3.4 Market Intelligence Repository (MIR)

In this hyper competitive environment, it is essential to monitor the market trends and changes in the demand of the particular product or service. By examining market behaviour and new innovative solutions, can help companies to set up innovation objectives and generate ideas to meet these objectives. This method has been applied by many companies. For instance, by looking at the popularity of Smart Phones and App Market; many banks have developed banking App to enable their customers to manage bank accounts by using their smart phone. Barclays' Pingit and NatWest's Mobile Money Transfer App are some of the examples which are inspired by market demand/behaviour.

Furthermore, MIR will contain links/details of patents. This knowledge could be used as a source of inspiration for employees to come up with new ideas and/or apply this knowledge in other domains. A detailed diagram of MIR is shown in Figure 5.13.

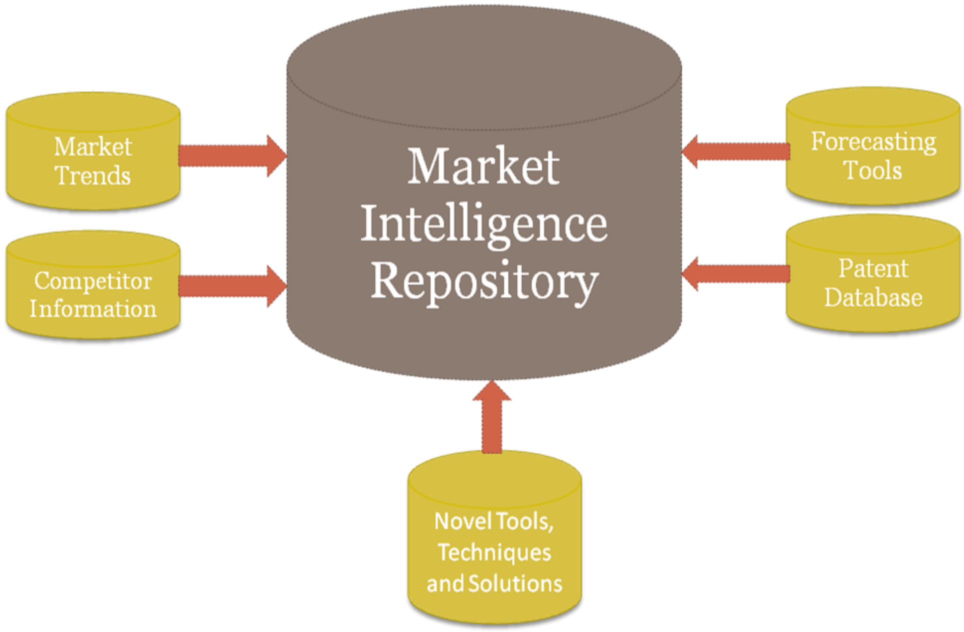

Figure 5.13 - Market Intelligence Repository

5.5.3.5 Participants Repository (PR)

As it is clear from the name, Participant Repository holds all the information about the users of the platform. The knowledge about individual's skills and expertise and their past experiences can be helpful when composing innovation team. The term individual refers to employees, customers, suppliers and other member of extended enterprises. A right selection of a team can make a huge difference in the progress and success of an innovation project. Depending on the requirements of innovation project, people can be searched and selected to build a team.

Every company has champions and experts. By keeping records of their past contributions and matching their experiences with current or new projects would help in building strong team and it will assure the success of an innovation project. A detailed picture of the participant repository is shown in Figure 5.14.

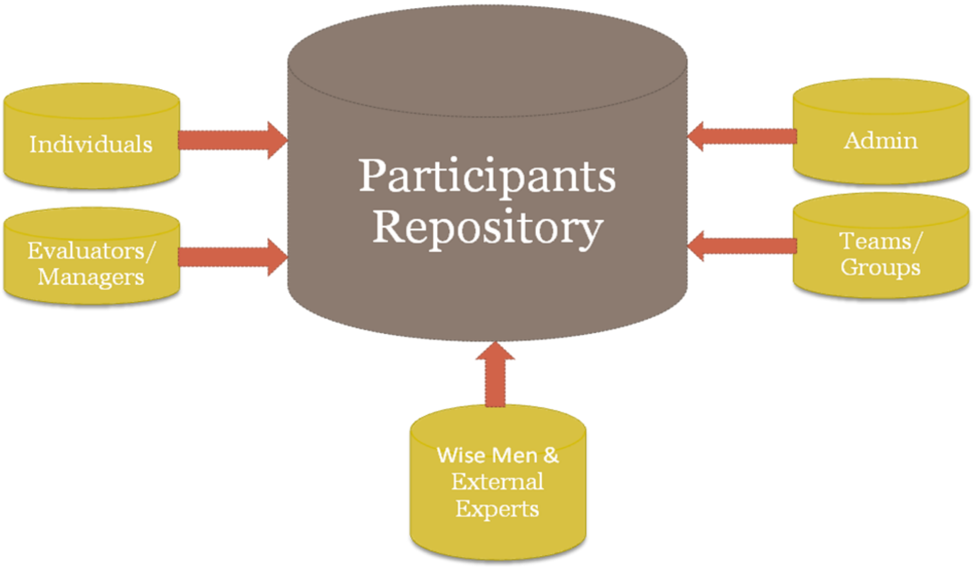

Figure 5.14 - Participant Repository

5.6 Summary

The chapter has provided details on the Innovation Process Map in manufacturing SMEs and proposed a combinatorial framework to systematise their innovation processes. The new framework is an extended version of ExtremeFactories innovation methodology which was primarily designed to meet the special requirements of manufacturing SMEs. This new version has integrated the knowledge management process to the innovation methodology. This mixture has proposed a new way to support companies to seek improvements (daily, tactical or strategic) on a continuous basis and by having access to useful knowledge with a view to help them to make the right decisions and hence prohibiting the generation of waste in the first place. This new combinatorial approach to innovation is an original contribution to existing methods in this field.

CHAPTER 6 - DEVELOPMENT OF KNOWLEDGE MODEL USING COMMONKADS METHODOLOGY

6.1 Introduction

This chapter provides details about the development of the knowledge model. The research has applied the CommonKADS methodology for design and development of the knowledge model. It has been widely applied in the European research projects for knowledge modelling. It allows the user to utilise structured knowledge engineering techniques, and has collection of customisable tools for knowledge management. It is also comprised of methods that execute a comprehensive analysis of knowledge intensive tasks and processes. It has a number of pre-defined templates' library which can be reused for collecting the data required for model development but are mainly for modelling processes to support decisions.

6.2 Knowledge Modelling

The CommonKADS methodology was applied on MBAS business case to develop the Entity Relationship model of its system design and specification process. To achieve this aim, three CommonKADS models have been developed. These models are described in the following sections.

6.2.1 Organisation Model

The organisational model suggests to examine the company from five key perspectives. It includes organisation's:

1. Activities,
2. Structure,
3. Processes,

4. Power/authority, and
5. Resources.

This section describes the organisation model by going through the sequence of work-sheets.

Table 6.1 - Worksheet OM-1: Problems: Organisational Context, and Possible Solutions

Organisation Model	**Problem and Opportunity Worksheet OM-1**
PROBLEM AND OPPORTUNITY	The Idea management and/or Innovation management systems are mainly designed to capture ideas from the employees and extended members of the organisation. They do not provide any means for users to look for more information related to their ideas. This results in users submitting ideas which are not relevant for the company; and do not match its innovation goals and objectives.
ORGANISATIONAL CONTEXT	Provide users access to relevant information and knowledge related to their ideas and offer them choice to look at these information and knowledge sources before submitting their ideas into the system.
SOLUTIONS	Design and develop knowledge repositories and links them with the Innovation system to enable employees to look at the information related to the company's innovation goals and objectives, relevant principles and practices, past similar ideas etc.

Table 6.2 - Worksheet OM-2: Variant Aspect of the Organisation

Organisation Model	**Variant Aspects Worksheet OM-2**
STRUCTURE	See Figure 6.1
PROCESS	See Figure 6.2
PEOPLE	See Figure 6.1: roles of people are specified for each of the organisation structure.
RESOURCES	i. **Databases:** o Past similar cases (or Previous System Designs) o Safety and regulatory requirements (e.g. Supply of Machinery (Safety) Regs, ATEX, HSG 178, CDM) o Funding sources - in case of MBAS list of funding bodies for the clients to finance new equipment(s)/solution(s)/product(s) from MBAS. ii. **Aessop system** - provide information about stock control / sales and service function and CRM.
INFORMATION AND KNOWLEDGE	i. Air Compressor – 10 Year life cycle cost Analysis charts - it helps in choosing a product based on customer requirements.
CULTURE AND POWER	Hierarchical organisation.

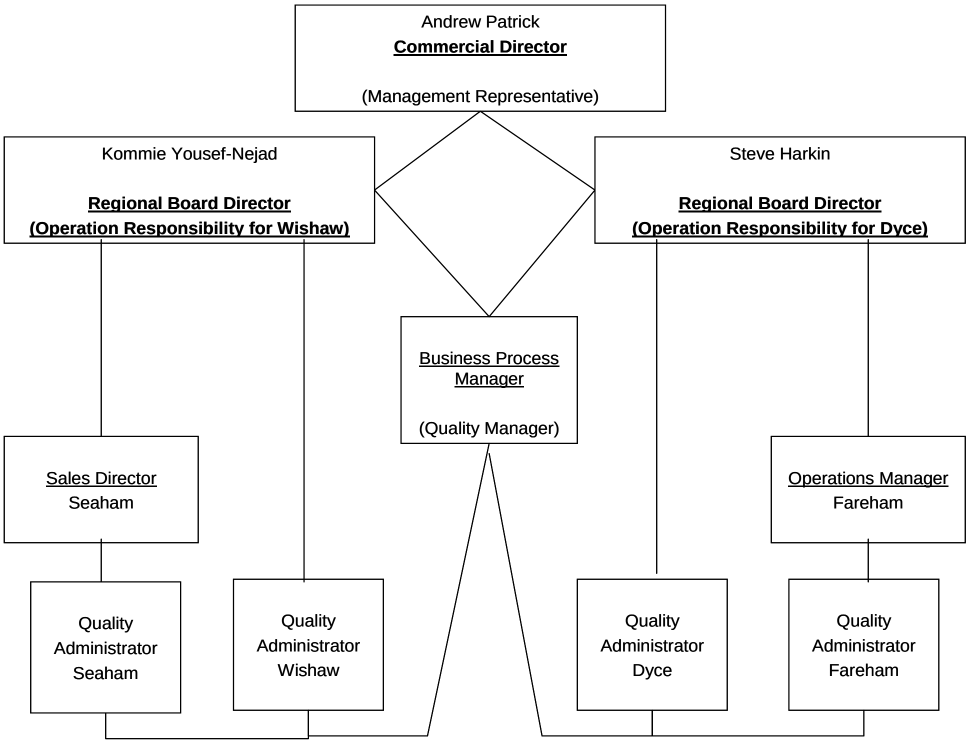

Figure 6.1 - MBAS Organisational Structure

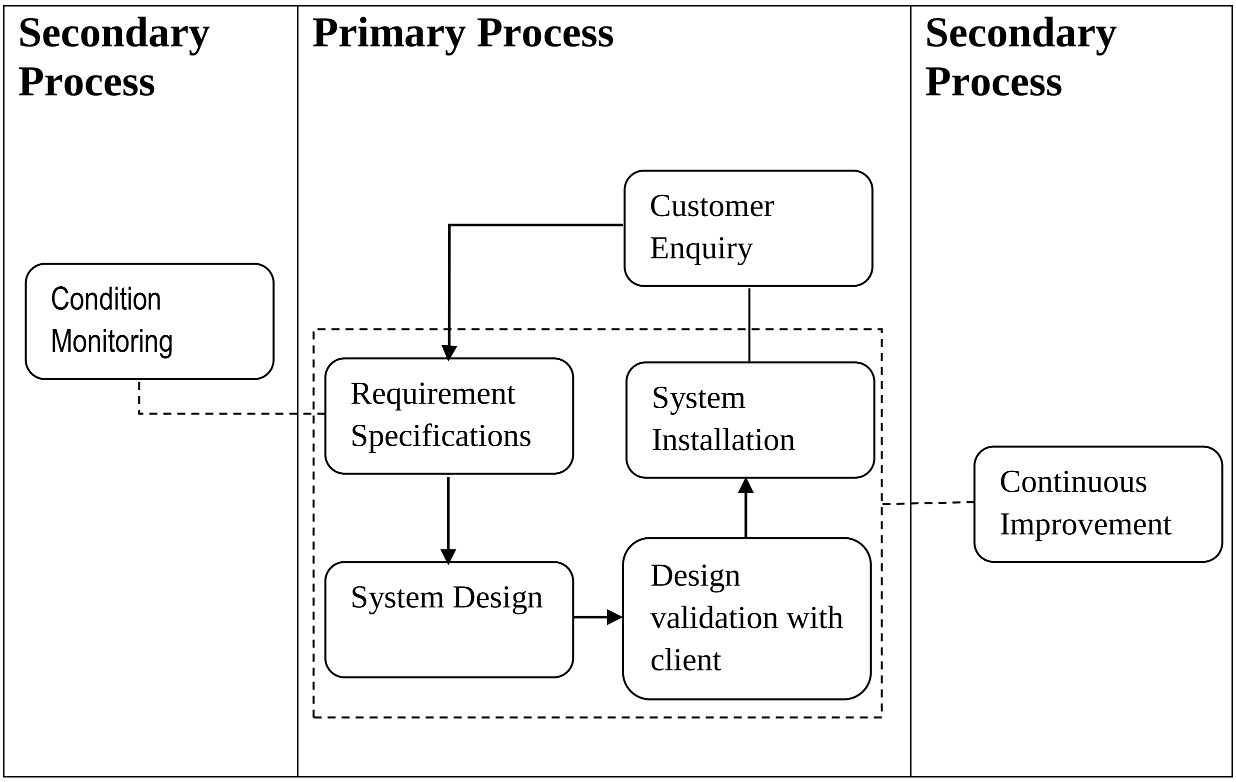

Figure 6.2 - Primary and Secondary Business Processes in the Current Situation

Table 6.3 - Worksheet OM-3: Process Breakdown.

Organisation Model		**Process Breakdown Worksheet OM-3**				
NO.	TASK	PERFORMED BY	WHERE?	INFORMATION AND KNOWLEDGE ASSET	INTENSIVE	SIGNIFICANCE
1	Client specifications	Sales Team	Sales Department		NO	
2	Detailed System Requirements	Engineering Team		Log Data	YES	
3	System Design	Engineering Team		–Enquiry Details –Client Specification –Data Logging –Minutes of Site Meetings –Site Risk Assessment –Legislative Requirements –‘Experience’/ Knowledge –Previous Installations –Supplier Data –Past cases –Design Principles and Practices	YES	5

Table 6.4 - Worksheet OM-4: Knowledge Assets

Organisation Model		**Knowledge Assets Worksheet OM-4**				
INFORMATION AND KNOWLEDGE ASSET	POSSESSED BY	USED IN	RIGHT FORM	RIGHT PLACE	RIGHT TIME	RIGHT QUALITY
Design Principles and Practices	Engineering Team	System Design	Yes	Yes	Yes	Yes
Past cases	Engineering Team	System Design	Yes	No - Saved in shared folder. Not easy to find	Yes	Yes
Legislative Requirements	Engineering Team	System Design	Yes	Yes	Yes	Yes
System Design Requirements	Engineering Team	System Design	Yes	Yes	Yes	Yes
Log Data	Engineering Team	System Design	Yes	Yes	Yes	Yes
Supplier's product information	Engineering Team	System Design	Yes	Yes	Yes	Yes

6.2.2 Task Model

The task model (TM) explores the "System Design" task in more detail and has two associated worksheets. The first worksheet facilitate to do a first task analysis of the task in question. The second sheet deals with knowledge bottleneck identification.

TM-1: First Task Analysis

Worksheet TM-1 in contains a description of System design. The description is at a more detailed level than in the organisation model. In the task model, the aim is to "zooming in" on a task and describe both the internal information of a task (control information, data manipulated), as well as external information such as the goal of the task, performance requirements, quality criteria, and constraints. The worksheet lists some typical examples of task information for the system design task.

Table 6.5 - Worksheet TM-1: Task Analysis

Task Model	Task Analysis Worksheet TM-1
TASK	System design
ORGANISATION	Primary business process; carried out in the engineering department by the engineering team.
GOAL AND VALUE	This task should ensure that the proposed design meet all the client requirements both technical and financial. The task is essential to deliver the design service at the required quality level.
DEPENDENCY AND FLOW	**Input tasks:** 1. Requirement Specifications; 2. Information from Data logging activity **Output tasks:** System design
OBJECTS HANDLED	**Input objects**: Client requirements, minutes of client meetings, **Output objects:** Validated system design
TIMING AND CONTROL	Carried out upon the client's request or the sale lead from sales department. The process starts with the Condition Monitoring activity. The engineering team monitors the client’s existing system using state-of-the-art data acquisition equipment for one week. It collects information to develop an accurate picture of how the client's current system truly operates. During this activity, the team carries out several interviews with the client to discover unspecified needs. At the end of this activity, the information collected by the monitoring tool is analysed by the engineering team. As an output of this activity, a detailed report presenting a clear picture of how the current air system operates and proposing ways to improve system performance is developed.

AGENTS	Engineers, Manager, Director In the new situation: knowledge system
KNOWLEDGE AND COMPETENCE	• IT and CAD knowledge • Creative problem solving ability • Subject specific technical knowledge and expertise • Good understanding of manufacturing processes
RESOURCES	• Past cases • Legislative Requirements • Design Principles and Practices • Knowledge from Condition Monitoring activity • Supplier's product database
QUALITY AND PERFORMANCE	The task is not time-critical, but it is expected that the system is quick. System availability should be at least 95%.

TM-2: Knowledge Bottleneck Identification

This task model provides insights on the information and knowledge assets involved in the system design process. To achieve this, Worksheet TM-2 was selected that characterize the nature of information and knowledge sources concerning attributes associated with nature, form and availability of the knowledge.

Table 6.6 - Worksheet TM-2: Knowledge Item

Task Model	**Knowledge Item Worksheet TM-2**	
NAME POSSESSED BY USED IN DOMAIN	• Past cases • Legislative Requirements • Design Principles and Practices • Knowledge from Condition Monitoring activity • Supplier's product information	
Nature of the information and knowledge		**Bottleneck / to be improved?**
Formal, rigorous	X	
Empirical, quantitative		
Heuristic, rules of thumb		
Highly specialized, domain-specific	X	
Experience-based	X	
Action-based		
Incomplete		
Uncertain, may be incorrect		
Quickly changing		
Hard to verify		
Tacit, hard to transfer		
Form of the information and knowledge		
Mind	X	
Paper	X	
Electronic	X	
Action skill		
Other		
Availability of information and knowledge		
Limitations in time		
Limitations in space		
Limitations in access	X	X
Limitations in quality		
Limitations in form	X	X

The table above shows that the nature of this type of information and knowledge is formal and/or rigorous, and highly specialized. It is available in employees' mind, paper and electronic formats. The paper form is in itself not a problem, but by considering availability it is clear that there is a problem connected with the format. Therefore, it would be idle to have the all types of information and knowledge in electronic form so that it can be made available to a computer program. Finding bottlenecks is a central issue in knowledge analysis at this course-grained level. Improving bottlenecks related to knowledge is what really helps an organisation. Bottlenecks are thus a focus point for all knowledge-management activities.

6.2.3 Agent Model

The agent model does not add much new information to what is already contained in the organisation and task models. The agent model reorganises the information so that one can look at it from the perspective of the agents involved. The agents will eventually have to do their (new) jobs in the organisation. The success of the system depends on their willingness and ability to cooperate. The table below describes the worksheet AM-1 for the "Engineer" agent. This is the human role in the organisation most affected by the proposed solution.

Table 6.7 - Worksheet AM-1: The "Engineer" Agent.

Agent Model	Agent Worksheet AM-1
NAME	System Design Engineer
ORGANISATION	Engineering Department plays key role in system design and installation
INVOLVED IN	• Requirement gathering • System design
COMMUNICATES WITH	**Client:** meetings to gather specifications and unidentified needs, design validation **Database:** past cases, technical requirements, Safety and regulatory requirements; Data-logging and analysis reports
KNOWLEDGE	• IT and CAD knowledge • Subject specific technical knowledge and expertise • Awareness of design principles and practices • Knowledge about safety and regulatory requirements
OTHER COMPETENCES	• Good understanding of manufacturing processes • Creative problem solving ability
RESPONSIBILITIES AND CONSTRAINTS	Proposed solution should satisfy all client's requirements.

6.2.4 MBAS Entity Relationship Model

The entity relationship model, which is also known as entity-relationship (ER) diagram, is primarily applied to represent entities and relationships in a graphical format. The following diagram represents the previously identified information sources in graphical format and also defines the relationship between these sources.

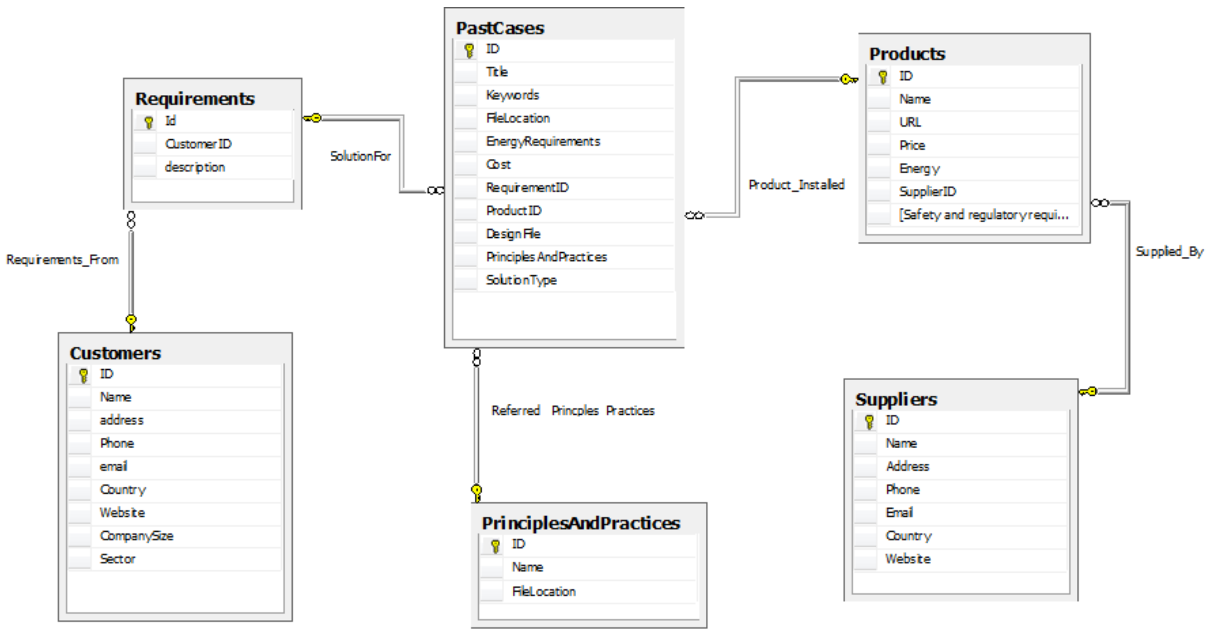

Figure 6.3 - MBAS Entity Relationship Model

6.3 Summary

This chapter described an innovative process that has applied the CommonKADS methodology and the CommonKADS analysis framework in the selected manufacturing SME. The chapter has raised important issues with existing idea management systems that are mainly designed to capture ideas and do not provide any means for users to look for more information related to their ideas. This results in employees submitting ideas which are not relevant for the company; and do not match its innovation goals and objectives. These findings have justified Objective 4 of the proposed research programme. The development of knowledge repository and linking it with the Innovation system is found to be a viable solution to enable employees to reuse the available information and knowledge assets to self-validate their ideas; and create a learning environment.

This chapter makes two notable contributions to the existing knowledge. Firstly, it has validated the CommonKADS methodology on the selected innovation process in which knowledge-intensive tasks are carried out to define the knowledge-management strategy.

Secondly, it has provided a database schema that can be adopted to manage information and knowledge assets used in the innovation process.

The results of this chapter will be used in the next chapter in the implementation of the proposed knowledge toolset.

CHAPTER 7 - KNOWLEDGE BASED INNOVATION APPROACH AND ITS TOOLSET IMPLEMENTATION

7.1 Introduction

This chapter illustrates the details of implementation of the proposed framework and the CKR. The developed system presents a creative environment to support innovation processes and promote learning in the organisation through the integration of discrete type and formats of information and knowledge assets used in the innovation process. This distinct type of information and knowledge assets are represented using Labelled Property Graph Model which intuitively maps data points and the connections between them to support employees' creative thinking.

The chapter covers the details related to design and development of the Knowledge based Innovation toolset and its applications to support innovation processes in manufacturing SMEs. The technologies adopted to implement the system are described and the implementation of knowledge representation and visualisation modules of the CKR is discussed.

7.2 Selected Implementation Scenario

"Product Finishing System Design and Specification Process" takes between 8 to 12 months of time to complete, therefore, due to time constraints it was not viable to model the entire process. To this end, it was decided to choose system design activity as a sample scenario for system implementation. The following diagram represents MBAS's system design process.

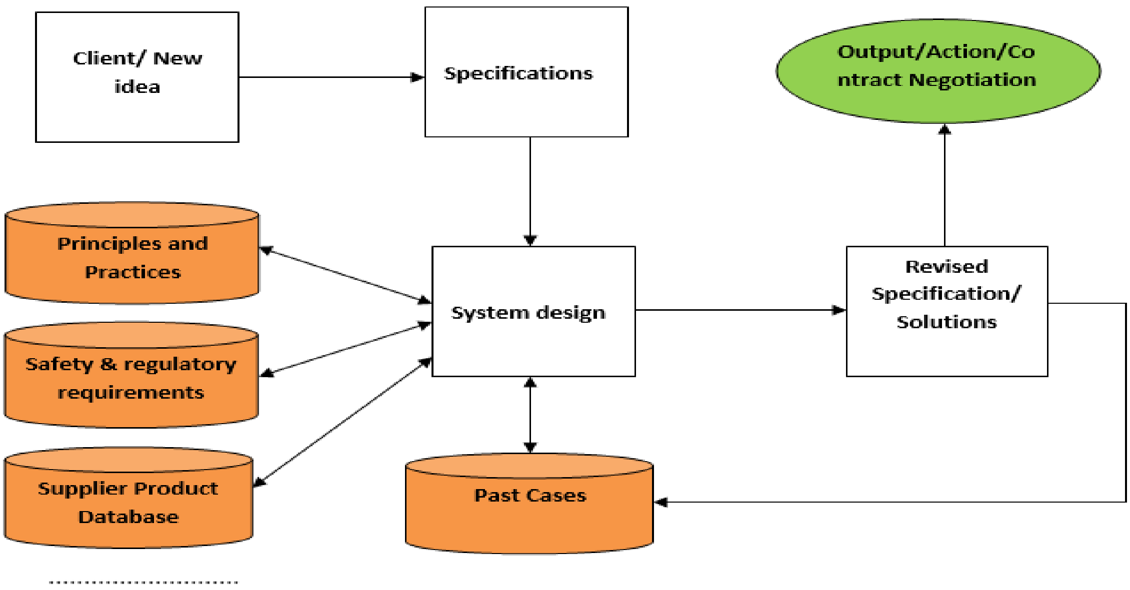

Figure 7.1 - MBAS's System Design Process

It is clear from the diagram that there are four main databases which have been used in the system design process. These are:

- Principles and Practices
- Safety and regulatory requirements
- Products
- Past cases

Some of other relevant information sources referred during the design process are:

- Suppliers' database
- Customers information

The following table shows storage formats of above-mentioned information and knowledge sources:

Knowledge source	**Storage format**
Principles and Practices	PowerPoint
Safety and regulatory requirements	Word, PDF
Products	HTML
Past cases	Word
Services	HTML
Suppliers	SQL DB
Customers	SQLDB

The above table shows that the information has been represented and stored in different formats. Having these information sources in different formats makes it harder, firstly to understand the relationships among these sources; secondly to get full access to all the information sources required for the innovation activities. In current environment, it is very difficult to know how product information relates to past cases which are captured in word formats; and how the past cases relate to customer data stored in the SQL databases.

In addition, the company senior representative, who participated in the case study, highlighted the issue with time spent for getting the information out from the above mentioned sources. The company do not have any server or a central place to save the information, therefore, the employees usually keep information such as past cases, on their computers. As there is no systematic approach in place to represent and store the information, the employees have to navigate through all the folders and sub folders, where the information might be stored, to search for the required information. This takes several minutes every time they look for the information. To this end, there is a need to represent data in such a way that these relationships become visible, and allows them to be discovered.

The research will now move towards the investigation of potential technologies that could be used to address the above mentioned issues. The next section provides details on available implementation technologies and describes how the proposed knowledge toolset has been implemented.

7.3 System Implementation Technology

Recent advancements in database technologies, especially in the area of knowledge representation and visualisation, provided the base for the implementation of the proposed system. In order to address the issues highlighted in the literature and identified from the research test beds, the research looked at potential technologies that stores data as well as relationships among them.

One of the possible solutions could be a traditional relational database system such as MSSQL and Oracle. These database systems store data in tables, which are composed of rows and columns, and define relationship among data and other sources using relationship keys. These keys are then use to infer relationships among different tables using JOIN statements. Although, the information and knowledge sources used in MBAS's System Design and Specification process, can be stored in relational database, but the JOIN queries will become very complex with increase in the numbers of information and knowledge sources. The researchers (Lysenko et al., 2016) have criticised the relational databases for being computationally expensive and hard to design when performing complex join operations.

To address deficiencies in the relational databases, NoSQL database technology came into existence. NoSQL database offer various approaches for data storage and representation: Key-value, Graph, Column, Document and Multi-model. The choice is highly depend on data storage and representation requirements. The Graph databases are considered as most suitable for defining and analysing relationships. Several researchers have demonstrated the power of Graph databases, especially in biological studies to represent and discover complex relationships among heterogeneous biological data. For example, Lysenko et al. (2016) demonstrated the use of graph database for storage and representation of disease networks. Whereas, Henkel et al. (2015) and Yoon et al. (2017) applied graph database in storing and integrating heterogeneous data; and Balaur et al. (2017) used it to model genetic and epigenetic data of colon cancer to discover correlation between genetic and epigenetic factors. All these researchers found Graph database a best fit for representing and discovering relationships among data.

The Graph database uses graph like structure to represent and store data. It has three main elements: nodes, edges and properties. The Graph database uses these elements to represent and store data. Each node represents entities (such as past cases, products, requirements), each edge represents relationship that connects two nodes, and each property represents named values. The edges or relationships are the key concept of graph database that directly relates entities (such as past cases) in the database. This form of data representation stores relationship as first-class entities in database, in contrast to traditional relational databases that stores link in data itself, and uses JOIN statements to collect data in the database. The graph database is very expressive and easy to model complex hierarchical structure than conventional relational databases and other NoSQL databases. The other databases, like 1970's network-model databases, also represent data in form of graph but they lack easy graph traversal over heavily interconnected data and operate at a lower level of abstraction. Whereas, the graph databases, by design, are found to be effective to store heavily interconnected data (Angles and Gutierrez, 2008), and perform simple and rapid retrieval of deeply linked data (Yoon et al., 2017).

The graph database technologies can be distinguished using two key properties - Graph Storage and Graph Processing Engine. The “Graph Storage” property signifies means of storage that database uses to store and manage graph. Most commonly used graph storage mediums are native graph storage, relational database and object-oriented databases. The native graph storage is specifically designed to store and manage graphs, thus offer faster transactions and data processing over relational or object-oriented databases. On the other hand, Graph Processing Engine indicates how graph data is processed. The type of Graph Processing Engine depends on the graph storage medium. The native graph databases uses native graph processing which is an efficient way to perform CRUD (Create, Read, Update and Delete) operations on the graph databases.

In this research, the graph database has been selected for the design and development of the CKR that will represent and store information and knowledge sources identified from the selected business case. The graph database has been implemented using Neo4j (https://neo4j.com/), a graph database management system. Unlike in other NoSQL databases, which offer no support to connect data at database level, Neo4j provides a native graph storage structure implementing an index-free adjacency to enable high-performance query execution. It is also an ACID (Atomicity, Consistency, Isolation, and Durability) compliant transactional database. According to the DB-Engines ranking[6], Neo4j has been ranked the most popular graph database in the technology world. Neo4j is written in Java - general-purpose computer-programming language; and is compatible with all major software development tools written in other languages. It can be accessed using Cypher Query Language through the binary 'bolt' protocol. Alternatively, one can use transactional HTTP endpoint to execute queries on the graph database. In Neo4j, the data is represented using

[6] "DB-Engines Ranking of Graph DBMS". DB-Engines. February 2016. Retrieved 2016-02-28.

nodes, edges and properties. It allows each node and edge to have multiple properties; where the nodes can also have recursive relationships.

To design and develop graph database, Neo4j Graph Platform has been selected, which is built around the Neo4j native graph database. It has number of components, as shown in the Figure 7.2. It includes:

- Neo4j Desktop - a mission control centre for developers.
- Native Graph Database – a database specially designed to store and manage graph.
- Neo4j Graph Analytics – a tool to get insights from the stored data
- Data integration tools – helps to move data from RDBMS data and other databases into graphs
- Graph Visualisation and Discovery tools – helps to visualise and explore connected data to identify relationships among data sources.

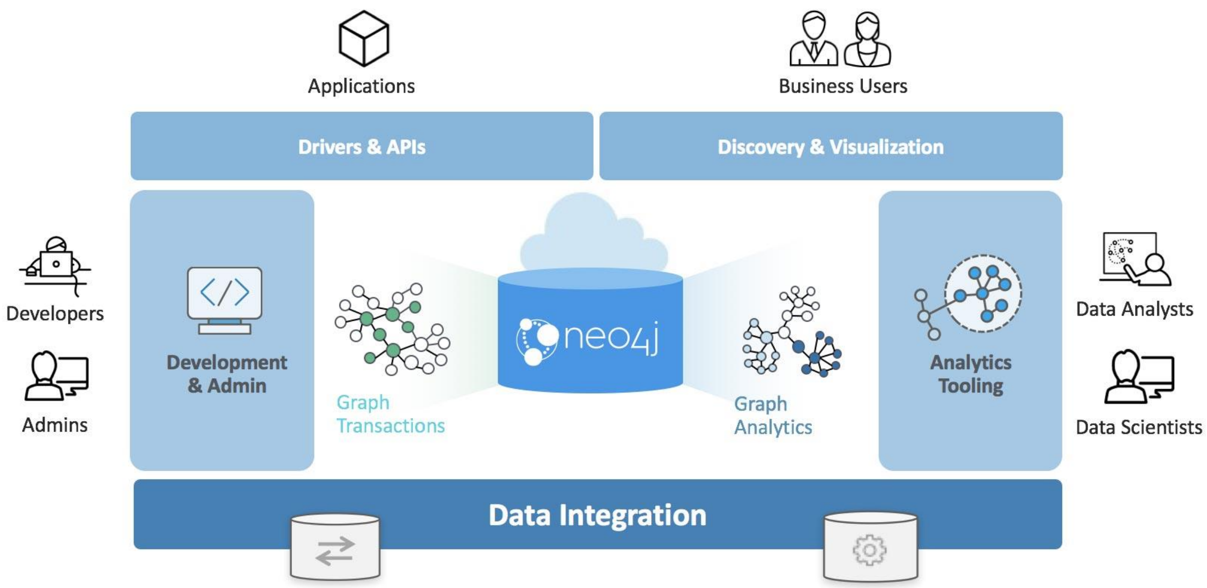

Figure 7.2 - Neo4j Graph Platform

Neo4j Graph Platform picture source: https://neo4j.com accessed on 18 May 2018.

7.4 Knowledge Representation

This section describes data graph modelling process that has been applied to model the information and knowledge sources that were identified in the previous section. The graph modelling process has utilised Labeled Property Graph Model to represent the information and knowledge sources in graph format. The Labeled Property Graph Model has four key components: nodes, relationships, properties and labels. All these components are shown in graph format in the Figure 7.3. Each node represents an entity (e.g. Past cases) which can hold any number of properties (e.g. type, cost). The properties provide information about the node and can contain this information in various formats such as Number, String, Boolean etc. Whereas, “relationships” are formed of direction, type, start and end nodes, and represent connections between two nodes to add semantic clarity to the graph structure. They can also have properties like nodes to serve additional information about the connection which provides useful metadata for graph algorithms and for adding constraints to graph queries. The Labels represent different roles of the node which can be tagged with the node to attach metadata, index or constraint information.

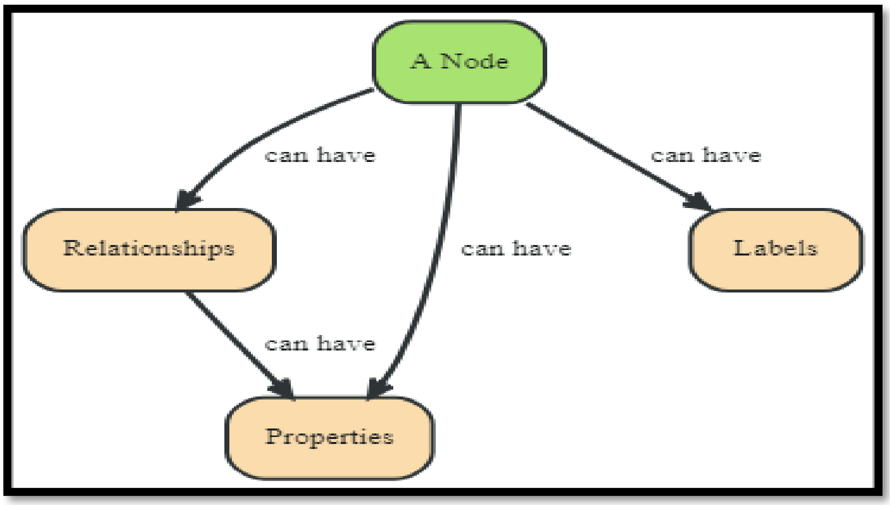

Figure 7.3 - Example Graph Database

7.4.1 Representation of ER Model into the Property Graph Model

Neo4j offers variety of options to represent information and knowledge in graph database. Some Knowledge Engineers prefer modelling the graph data by applying Labeled Property Graph Model concept on the data directly. While other, mainly with past experience in working with relational databases, find it easy to develop ER model and then transform ER Model into Property Graph Model.

The author has been working with relational databases from the last 10 years, therefore, decided to follow the later approach to model information and knowledge sources into graph format. In no way the research is claiming the later approach is a best way for knowledge representation in the graph database. The selection is simply based on author's past experience and simplicity of the selected approach.

The graph modelling process was started, as described in Chapter 6 with the design of ER diagram of identified information and knowledge sources being used in the innovation process. The ER diagram was then transformed into graph using Labeled Property Graph Model. The graphical representation of entities and relationships transformed from ER diagram is presented in the Figure 7.4 and Figure 7.5 - Property Graph Model with Nodes, Relationships and Properties.

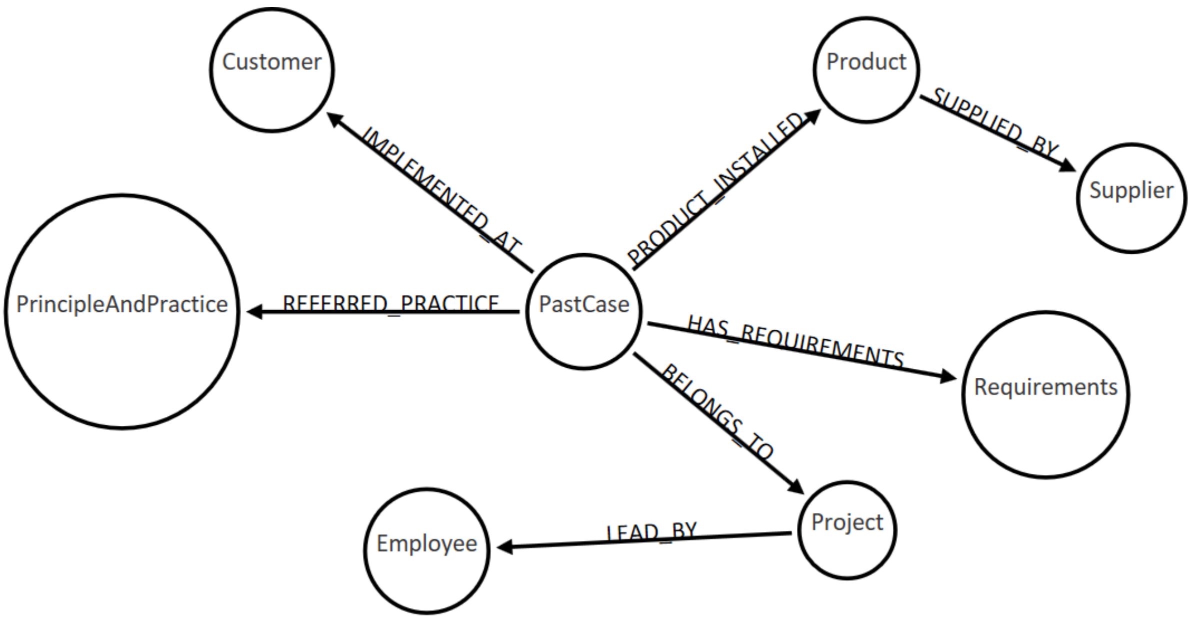

Figure 7.4 - Property Graph Model with Nodes and Relationships

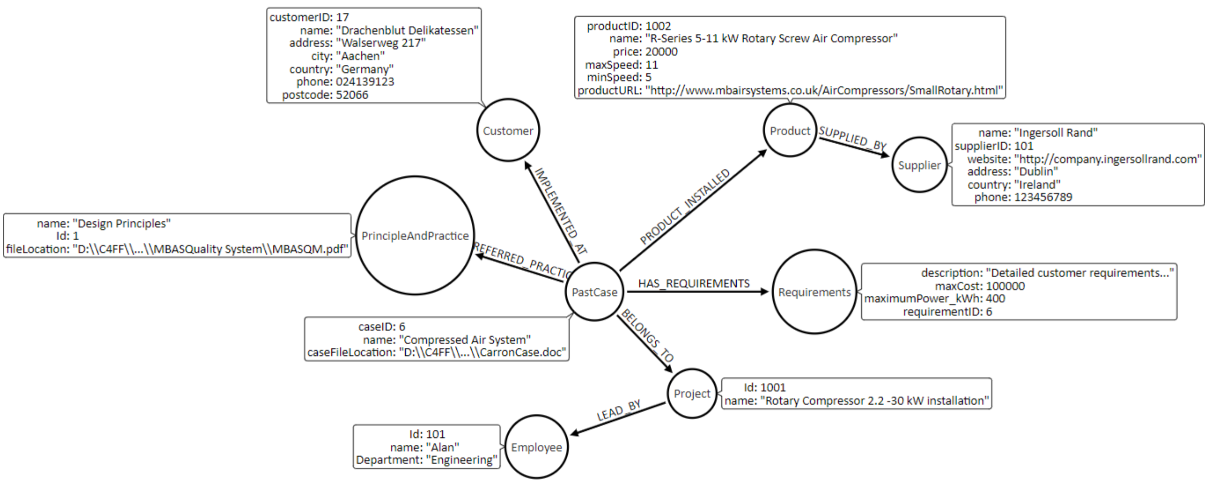

Figure 7.5 - Property Graph Model with Nodes, Relationships and Properties

There are eight main nodes (represented using circle): Past Case, Requirements, Customer, Principle and Practice, Project, Employee, Product and Supplier. Each node has number of attributes (represented using rectangular shaped box) which contains semantically relevant information about the node.

The objectives behind representing information using connected graphs:

- Provide the engineers’ access to similar past implemented solutions.
- Promote learning in the organisation by giving employees option to look at information related to their ideas e.g. Slides about design principles and practices.

Example queries that can be executed on the above graph database:

- Range of solutions for a given cost.
- Range of solutions for given cost and annual energy consumption.
- Range of solutions for given cost, annual energy consumption and type of solution.
- List out possible upgrade options to meet given energy requirements.
- **Results**:
    - List of solution matching to the search criteria
    - Links to explore related relevant information such principles and practices slides etc. -> *promoting learning in the organisation.*

7.5 Knowledge Storage

The knowledge storage has been handled using Cypher – a graph query language. Cypher is a declarative graph query language which is similar to SQL query language but optimised for the graph database. Cypher is invented by a company called Neo Technology, to manage its graph database and later become an open source project (http://www.opencypher.org/) in October 2015. Since 2015, it has been managed collaboratively. Now it has been adopted and used by several well-known graph database providers such as SAP HANA and AgensGraph to manage their graph databases.

Cypher is specifically designed to be very visual, intuitive and declarative. One can express what to achieve rather than how to achieve it. Unlike SQL, navigating connected data is very easy in Cypher due to its natural pattern-matching ability. Cypher allows users to access and manipulate database and execute queries to retrieve data, insert new nodes, update existing nodes, and delete records in the graph database.

Cypher is based on Property Graph Model and contains nodes, relationships, paths, maps, lists, integers, floating-point numbers, Booleans and strings. The Cypher has been continuously developed by its community through a Cypher Improvement Proposal (CIP)[7]. Anyone can join and be author to raise an issue for new Cypher feature. The request is then reviewed by openCypher Implementers Group and once accepted, added to openCypher repository for implementation.

A cypher query to setup graph database, presented earlier in Figure 7.5, is given below:

```
CREATE (`0` :PastCase {caseID:'6',caseFileLocation:"D:\\C4FF\\PhD\\Primary Research\\Case Studies\\Phd\\MBAS\\Material\\CarronCase.doc",caseKeywords:"Compressed Air System"}) , (`8` :Product {productID:'1002',name:"R-Series 5-11 kW Rotary Screw Air Compressor",price:'20000',maxSpeed:'11',minSpeed:'5',productURL:"http://www.mbairsystems.co.uk/AirCompressors/SmallRotary.html"}) , (`9` :Requirements {description:"Detailed customer requirements are described in customer requirement document",maxCost:'100000',maximumPower_kWh:'400',requirementID:'6'}) , (`10` :Supplier {name:"Ingersoll Rand",supplierID:'101',website:"http://company.ingersollrand.com",address:"Dublin",country:"Ireland",phone:'123456789'}) , (`11` :Customer {customerID:'17',name:"Drachenblut Delikatessen",address:"Walserweg 217",city:"Aachen",country:"Germany",phone:'024139123',postcode:'52066'}) , (`12` :PrincipleAndPractice {name:"Design Principles",Id:'1',fileLocation:"D:\\C4FF\\PhD\\Primary Research\\Case Studies\\Phd\\MBAS\\Material\\MBASQuality System\\MBASQM.pdf"}) , (`14` :Project {Id:'1001',name:"Rotary Compressor 2.2 -30 kW installation"}) , (`15` :Employee {Id:'101',name:"Alan",Department:"Engineering"}) , (`0`)-[:`PRODUCT_INSTALLED` ]->(`8`), (`0`)-[:`HAS_REQUIREMENTS` ]->(`9`), (`8`)-[:`SUPPLIED_BY` ]->(`10`), (`0`)-[:`IMPLEMENTED_AT` ]->(`11`), (`0`)-[:`REFERRED_PRACTICE` ]->(`12`), (`0`)-[:`BELONGS_TO` ]->(`14`), (`14`)-[:`LEAD_BY` ]->(`15`)
```

[7] "Cypher Type System". GitHub. Retrieved 2017-01-31.

After executing the above Cypher query, the data will get store in the graph database. The following table shows a tabular representation of the graph database.

Table 7.1 - Graph Database in Tabular Format

N
(0:PastCase {caseFileLocation:"D:\\C4FF\\PhD\\Primary Research\\Case Studies\\Phd\\MBAS\\Material\\CarronCase.doc", caseID:"6", caseKeywords:"Compressed Air System"})
(1:Product {maxSpeed:"11", minSpeed:"5", name:"R-Series 5-11 kW Rotary Screw Air Compressor", price:"20000", productID:"1002", productURL:"http://www.mbairsystems.co.uk/AirCompressors/SmallRotary.html"})
(2:Requirements {description:"Detailed customer requirements are described in customer requirement document", maxCost:"100000", maximumPower_kWh:"400", requirementID:"6"})
(3:Supplier {address:"Dublin", country:"Ireland", name:"Ingersoll Rand", phone:"123456789", supplierID:"101", website:"http://company.ingersollrand.com"})
(4:Customer {address:"Walserweg 217", city:"Aachen", country:"Germany", customerID:"17", name:"Drachenblut Delikatessen", phone:"024139123", postcode:"52066"})
(5:PrincipleAndPractice {Id:"1", fileLocation:"D:\\C4FF\\PhD\\Primary Research\\Case Studies\\Phd\\MBAS\\Material\\MBASQuality System\\MBASQM.pdf", name:"Design Principles"})
(6:Project {Id:"1001", name:"Rotary Compressor 2.2 -30 kW installation"})
(7:Employee {Department:"Engineering", Id:"101", name:"Alan"})

Up till now, the chapter has covered the details about technologies used for information and knowledge storage and representation. The next section will now provide details on technologies applied for information and knowledge visualisation and discovery.

7.6 Knowledge Visualisation and Discovery

To discover and visualise connected data, the proposed system has used Neo4j Browser. The Neo4j Browser is a powerful visualisation tool to present connected nodes and discover their relationships. It allows the user to visualize connected data, simplifies Cypher commands and offers query development tools beyond the command line.

It is a command driven client, bundled with number of features with enough ability to develop a Neo4j-based application. It is a developer focused tool and offer means for querying database, visualisation, and data interaction.

Neo4j Browser can be defined as a mashup of a REPL and a lightweight IDE, with capability of graph visualisation. It has three key components: Query Editor, Results Stream, and Actions Bar. The editor allows users to write and run Cypher queries to retrieve data from the graph database. The results of the Cypher queries are then displayed in result frame in the stream. The results are displayed either in tabular format, showing table of property data, or in graphical format, displaying nodes and relationships. The user can also expand the nodes, by selecting a node and clicking on "Expand Node" option, to explore other associated nodes. The actions bar contain different functional panel for common activities such access "Help" documents, interact with REST API, and view metadata and basic information e.g. nodes, relationships and property keys.

A screenshot of Neo4j browser window and all three components are presented in Figure 7.6.

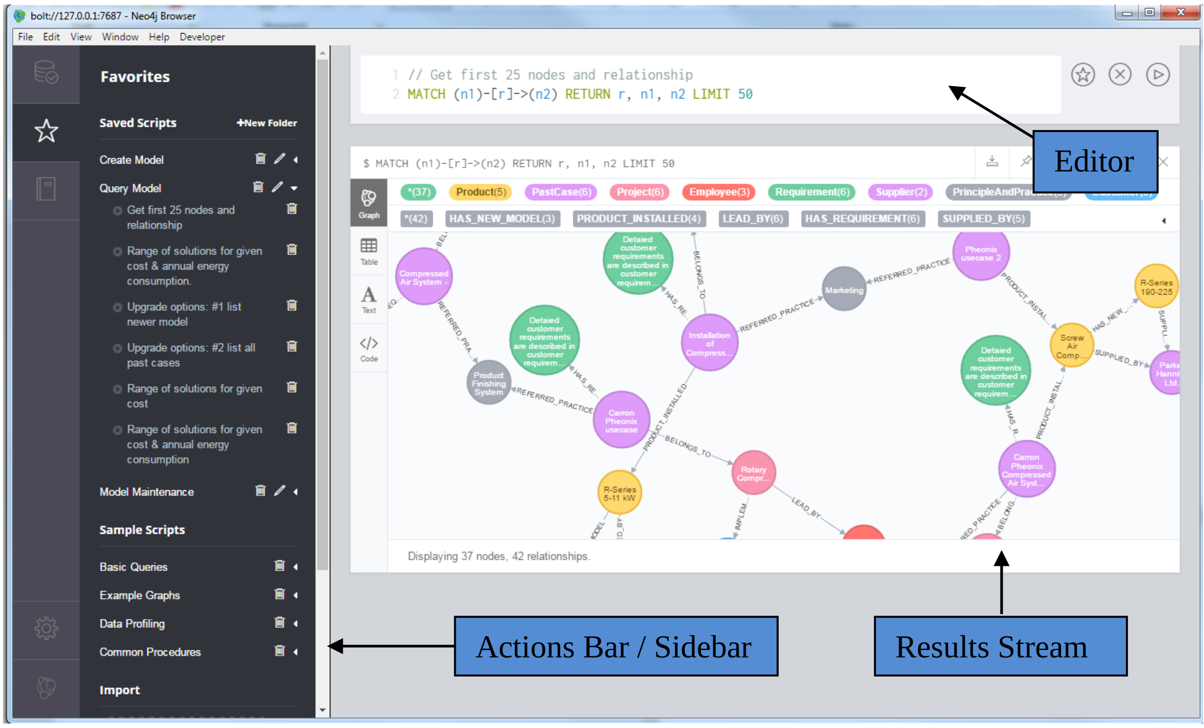

Figure 7.6 - Neo4j Browser Interface

To display results in the stream, the Neo4j browser send user's query to the Neo4j database. The Neo4j database processes the query and sends back data in JSON format. The Neo4j browser then creates an in-memory JavaScript visualisation and presents it onto the stream. The following query shows discovery and visualisation functionality in action. The query matches all the nodes and relationships, created in the section 7.5 and display them as a graph.

Cypher Match Query:

```
Match (n) return n;
```

Graph visualisation by Neo4j Browser.

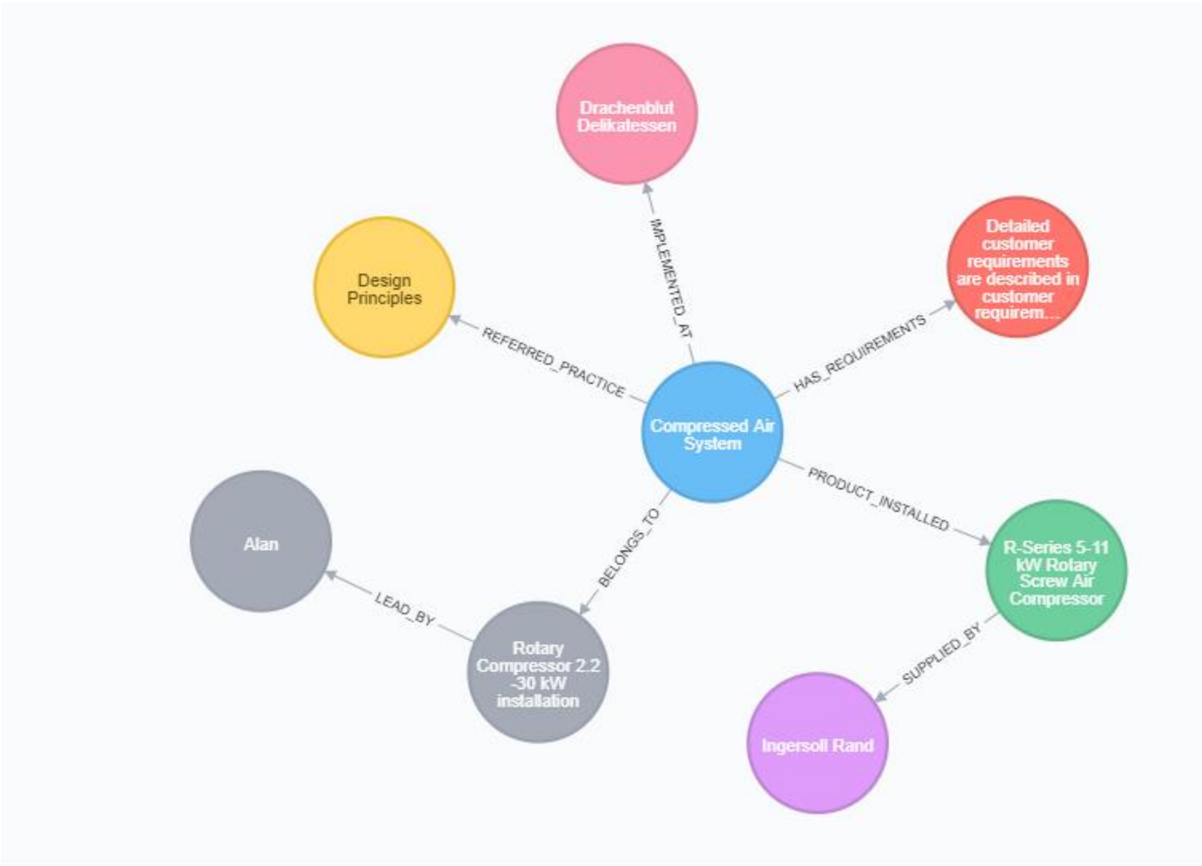

Figure 7.7 - Nodes and Relationship Rendered as a Graph by Neo4j Browser

7.7 Summary

This chapter has provided details of the implementation of a theoretical framework proposed in Chapter 5 and demonstrated how it can be applied in practice. Literature review has shown that Organisation Learning and Knowledge Management have a positive effect on the organisations' innovation outcomes. This research programme has developed a prototype powered with Neo4j Property Graph Model for knowledge storage and visualisation thus making ideas tangible; and has demonstrated how this works in practice. The presented system is validated in participating manufacturing SMEs. The results from testing and validation activities are presented in next the chapter and have made original contribution to the existing knowledge in this field.

CHAPTER 8 - VALIDATION OF THE PROPOSED RESEARCH

8.1 Introduction

Chapter 8 discusses the evaluation results of the proposed knowledge storage and utilisation functionalities of the CKR and its potential to support innovation process in manufacturing SMEs. Two steps validation approach is applied to evaluate the feasibility and effectiveness of the developed tool. In the first step, Laboratory based system validation approach is applied using dataset collected from one of the participating organisation. The second step involves system demonstration followed by semi-structured interviews with members of participating organisations, with view to gather their feedbacks and to reduce bias in the validation results. The results from both approaches are then used as a means of validation of the proposed knowledge based approach to support innovation.

8.2 Laboratory Based Validation

In the first phase of system validation, laboratory-based validation approach is applied. This process involves collection and evaluation of data from one of the participating organisation to establish scientific evidence that proposed system is consistently perform as expected and meets pre-defined specifications for knowledge storage and utilisation.

The developed system prototype enables innovators to explore past cases and relevant knowledge related to the innovation processes. It provides users knowledge storage and utilisation tool which is adaptable to any process in the organisation. A “System Design and Specification process” has been selected for system demonstration and validation. The ultimate goal was to test system capabilities for knowledge storage, knowledge representation so the relationship among different information and knowledge sources become visible;

knowledge extraction to identifying knowledge related to search query, and knowledge visualisation to present knowledge to user’s search query in a user-friendly way.

The data from “System Design and Specification Process” has been collected to validate the developed system prototype. The process involves number of activities from specification to installation. The System design activity has been selected as it closely matches to the research objectives.

8.2.1 Validation Objectives

The main purpose of validation is to test system capability to support “System Design” activities by providing innovators access to relevant knowledge for ideation process. This will be achieved by storing knowledge about past cases, design principles and practices, rules and regulations, products, process etc. in the CKR. The users will then have a choice to refer to this knowledge before presenting their idea. Thus, the key validation objectives are to:

- Demonstrate system capability to store new knowledge in a structured way.
- Validate knowledge representation functionality to represent information and knowledge available in different formats in such a way that the relationships among stored information and knowledge sources become visible.
- Test knowledge extraction service and its capability to extract knowledge related to users’ search query from the CKR.
- Explore how knowledge visualisation module can enhance firm innovation capacity by allowing users to explore knowledge relevant to their design activity.

A series of experiments are carried out to achieve above mentioned objectives. These are described in detail in the sections below.

8.2.2 Experiment 1 – Knowledge Storage Functionality Validation

8.2.2.1 Test Scenario Context/Description

The Design and Specification Process utilise various information and knowledge sources, as identified in Chapter 7 - Section 7.2, in the design process. The innovation team uses these sources in the ideation phase to come up with new ideas and to validate them. This test scenario deals with storage of these assets in the CKR.

8.2.2.2 Acceptance Criteria

The system facilitates users to add new knowledge and stores it in the CKR.

8.2.2.3 Preconditions for Test Scenario Execution

- Software system is running
- List of information and knowledge sources

8.2.2.4 Test Results

This experiment is designed to test system capability to let users store new knowledge in the CKR in structured way. To store new knowledge, database structured is designed. It includes identification and definition of nodes, relationships and keys.

Sample query to add new node – PRODUCT

```
//CREATE Product
USING PERIODIC COMMIT
LOAD CSV WITH HEADERS FROM
'file:///MBAS_DATA_MODEL/Product.csv' AS row
CREATE (:Product {productID: row.ID, name: row.Name, productURL: row.ProductURL,
price:TOFLOAT(row.Price), minSpeed:TOINTEGER(row.MinSpeed),
maxSpeed:TOINTEGER(row. MaxSpeed) });
```

Sample Query to add new relationship between PRODUCT and SUPPLIER

```
//CREATE PRODUCT AND SUPPLIER RELATIONSHIP
USING PERIODIC COMMIT
LOAD CSV WITH HEADERS FROM
'file:///MBAS_DATA_MODEL/Product.csv' AS row
MATCH (product:Product { productID: row.ID})
MATCH(supplier:Supplier {supplierID:row. SupplierID})
MERGE (product) – [:SUPPLIED_BY] -> (supplier);
```

By repeating above mentioned queries, full database is created. All the nodes, keys and relationships are shown in the pictures below:

Figure 8.1 - List of Nodes

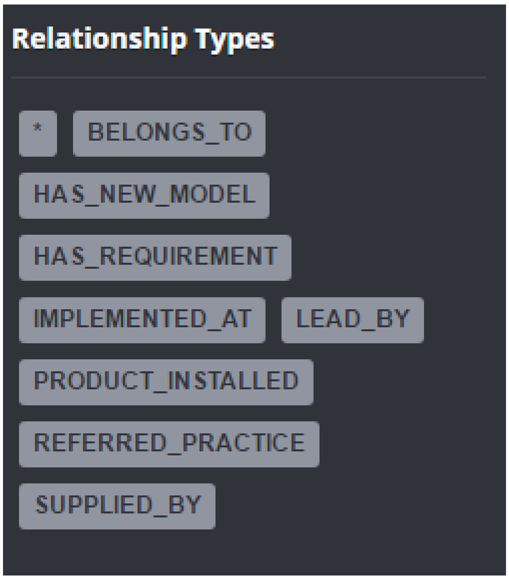

Figure 8.2 - List of Relationships

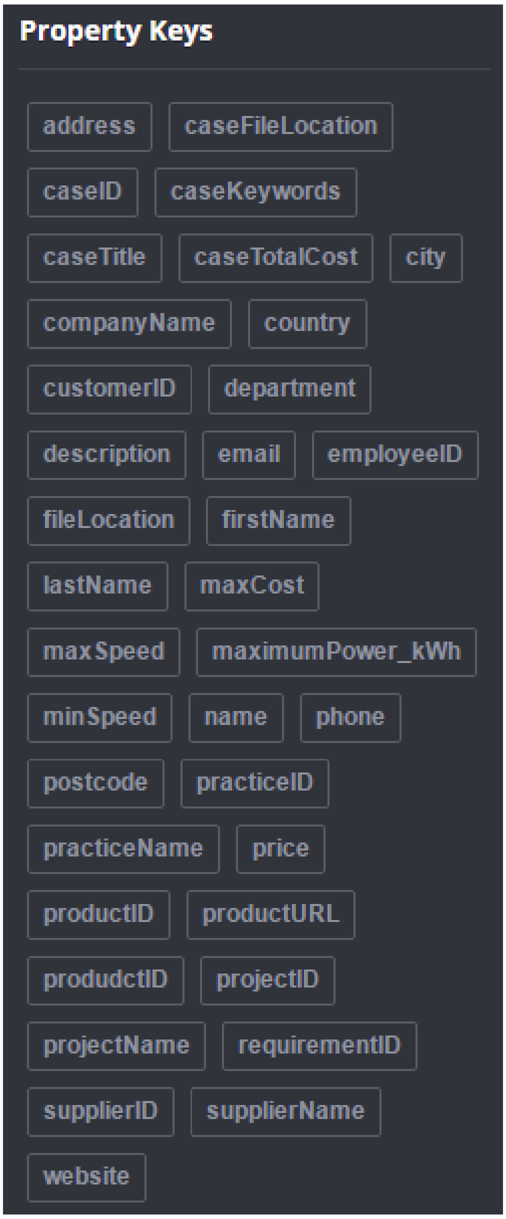

Figure 8.3 - List of Keys

The next step is to query the database to check if the knowledge has been stored. The following query is executed to search knowledge about past cases in the database.

```
MATCH (n:PastCase) RETURN n LIMIT 25
```

The results of the search query are shown in the table below:

Table 8.1 - List of Stored Past Cases in Text Format

"Pastcases"
{"caseTitle":"Carron Pheonix Compressed Air System","caseTotalCost":70000,"caseKeywords":"Compressed Air System","caseFileLocation":"D:\C4FF\PhD\Primary Research\Case Studies\Phd\MBAS\Material\Carron_Case.doc","caseID":1}
{"caseTitle":"Installation of Compressed Air System","caseTotalCost":150000,"caseKeywords":"Compressed Air System","caseFileLocation":"D:\C4FF\PhD\Primary Research\Case Studies\Phd\MBAS\Material\Carron_Case.doc","caseID":2}
{"caseTitle":"Carron Pheonix usecase","caseTotalCost":35000,"caseKeywords":"Compressed Air System","caseFileLocation":"D:\C4FF\PhD\Primary Research\Case Studies\Phd\MBAS\Material\Carron_Case.doc","caseID":3}
{"caseTitle":"Stainless Steel Sink Manufacturer usecase","caseTotalCost":50000,"caseKeywords":"Compressed Air System","caseFileLocation":"D:\C4FF\PhD\Primary Research\Case Studies\Phd\MBAS\Material\Carron_Case.doc","caseID":4}
{"caseTitle":"Pheonix usecase 2","caseTotalCost":75000,"caseKeywords":"Compressed Air System","caseFileLocation":"D:\C4FF\PhD\Primary Research\Case Studies\Phd\MBAS\Material\Carron_Case.doc","caseID":5}
{"caseTitle":"Compressed Air System - case 6","caseTotalCost":100000,"caseKeywords":"Compressed Air System","caseFileLocation":"D:\C4FF\PhD\Primary Research\Case Studies\Phd\MBAS\Material\Carron_Case.doc","caseID":6}

It can now be concluded that the experiments to validate the knowledge storage functionalities are passed. The proposed system is capable of adding and storing new knowledge into the CKR.

8.2.3 Experiment 2 – Knowledge Representation Functionality Validation

8.2.3.1 Test Scenario Context/Description

The current practices of information and knowledge storage in the selected process do not have a unified way to store knowledge. The knowledge is available in different formats such as .doc, .ppt, .xls, .sql etc. These formats make it impossible to find how the knowledge stored in the database is linked to knowledge stored in .doc format. The test scenario deals with representation of information and knowledge sources in such a way that relationships among these sources become visible. This will enable users to extract all relevant knowledge from the CKR to satisfy their knowledge needs.

8.2.3.2 Acceptance Criteria

The stored knowledge has been represented in a structured way. The relationships among information and knowledge sources are discoverable.

8.2.3.3 Preconditions for Test Scenario Execution

- Software system is running
- List of information and knowledge sources
- Relationships between information and knowledge sources are defined

8.2.3.4 Test Results

The experiment is carried out to test system capability to represent knowledge in structured way. In order to achieve this objective, new knowledge is added and stored into the CKR as demonstrated in Experiment 1. The following query is executed to check how system is representing the stored knowledge.

```
// Get first 25 nodes and relationships
MATCH (n1)-[r]->(n2) RETURN r, n1, n2 LIMIT 50
```

The results of above query are shown in the picture below:

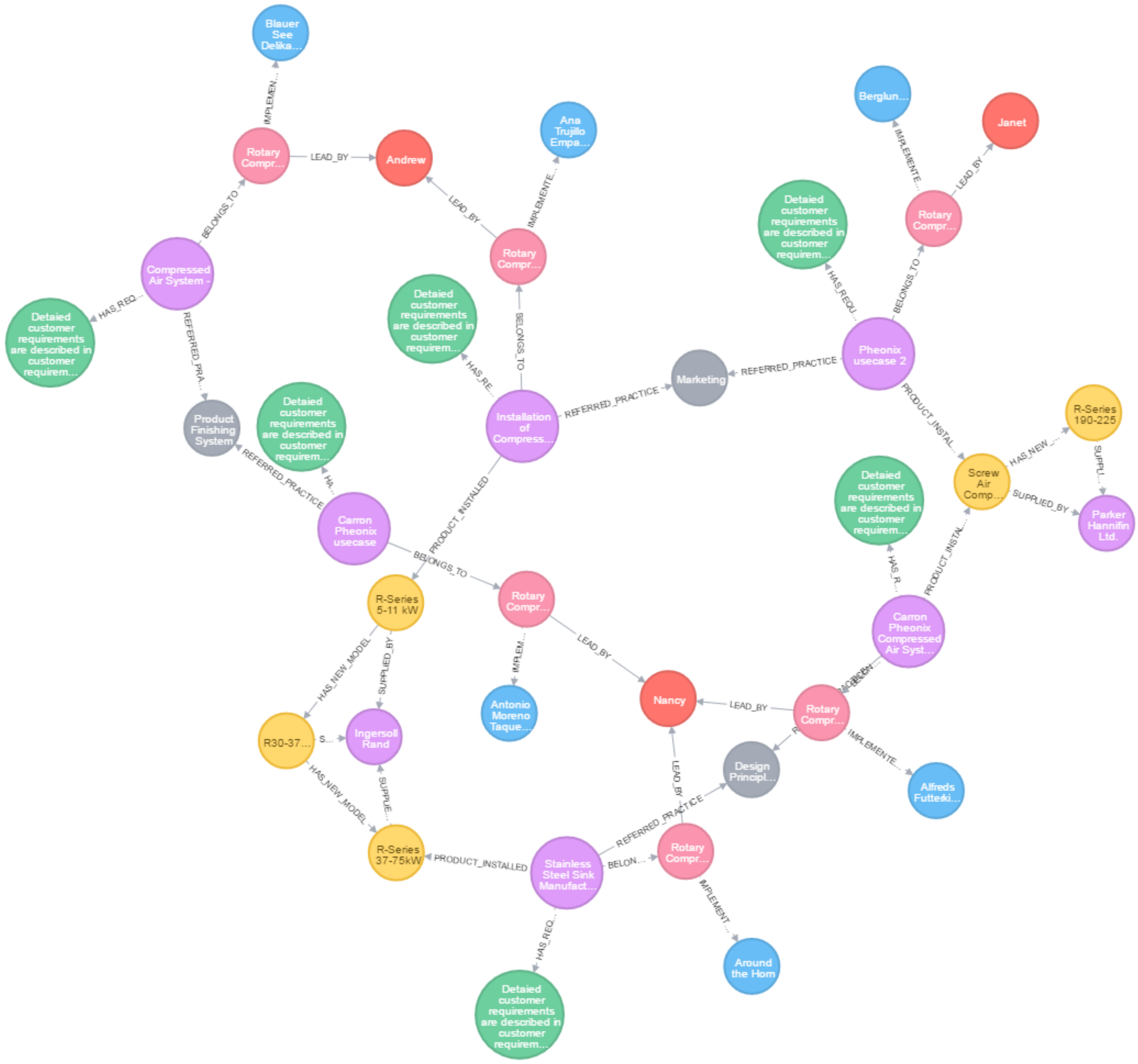

Figure 8.4 - Knowledge Representation using Graph Based Models

As it is clear from the picture, the knowledge about Products, Past cases, Employees, Suppliers etc are now linked together. As stated before, this information was available in different formats making it difficult to understand the relationships. The graph based knowledge representation approach has uncovered these hidden relationships by defining relationship keys thus making knowledge retrieval possible.

8.2.4 Experiment 3 – Knowledge Extraction Functionality Validation

8.2.4.1 Test Scenario Context/Description

This test scenario validates system capability to discover knowledge from the CKR to support ideation process in the system design activities.

8.2.4.2 Acceptance Criteria

New knowledge to support user activities can be extracted from the CKR.

8.2.4.3 Preconditions for Test Scenario Execution

- Software system is running
- At least 2 information and/or knowledge sources are stored in the CKR

8.2.4.4 Test Results

To validate the knowledge extraction functionality, the following queries are executed:

Query to extract range of solutions for given cost.

```
// Range of solutions for given cost
MATCH (ps:PastCase)
WHERE ps.caseTotalCost > 1000
RETURN ps
```

Query Results

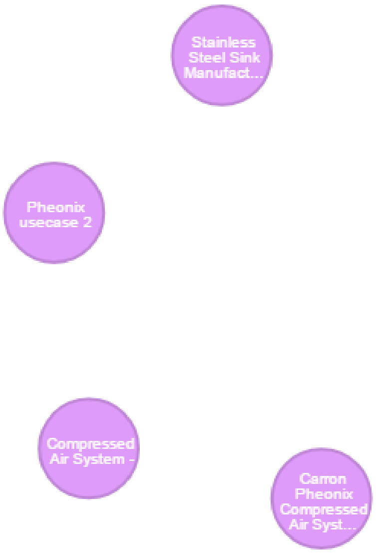

Figure 8.5 - List of Solutions for Given Cost

Query to extract range of solutions for given cost and annual energy consumption.

```
// Range of solutions for given cost & annual energy consumption

MATCH (ps:PastCase)-[r:PRODUCT_INSTALLED]->(p:Product)

WHERE p.minSpeed >20 and ps.caseTotalCost > 50000

RETURN ps

LIMIT 25
```

Query Results

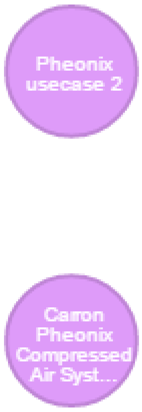

Figure 8.6 - List of Solutions for Given Cost and Annual Energy Consumption

The above-mentioned queries and their outputs have clearly demonstrated system's capability to extract knowledge from the CKR. The innovation team can use this system to extract similar past cases and learn from them to generate new ideas.

8.2.5 Experiment 4 – Knowledge Visualisation Functionality Validation

8.2.5.1 Test Scenario Context/Description

This test scenario validates knowledge visualisation module and its practicality to enhance firm's innovation capacity by allowing users to explore knowledge relevant to their design activities. This test further verify system capability to present relationships among information and knowledge sources, so they are visible to users.

8.2.5.2 Acceptance Criteria

The system can extract and present knowledge to the user. The relationships between information and knowledge sources are visible.

8.2.5.3 Preconditions for Test Scenario Execution

- Software system is running
- At least 2 information and/or knowledge sources are stored in the CKR

8.2.5.4 Test Results

The functionality to extract information about new models and possible upgrade options for existing product(s) at customers' premises can enhanced firm's innovation capacity and can also accelerate the whole solution design and implementation process. To achieve this, the following queries are developed, and their results are discussed below:

Query to find newer product model currently installed at customer premises.

// Upgrade options: list newer model

MATCH (ps:PastCase)-[r:PRODUCT_INSTALLED]->(p:Product)-[r2:HAS_NEW_MODEL]->(p2:Product)

WHERE ps.caseID = 1

RETURN p,p2

LIMIT 25

Query Results

As shown in the figure, the query has discovered new model of existing product installed at customer.

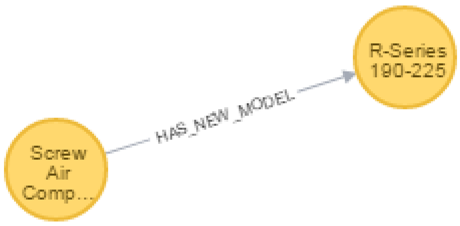

Figure 8.7 - Newer Model of Product Currently Installed

Query to discover possible upgrade options to meet given energy requirements.

// Upgrade options: list all past cases

```
MATCH (ps:PastCase)-[r:HAS_REQUIREMENT]->(req:Requirement)
MATCH (ps:PastCase)-[r2:PRODUCT_INSTALLED]->(p:Product)
WHERE  req.maximumPower_kWh > 239
RETURN p,ps
LIMIT 25
```

Query Results

Similar to previous search results, the query has discovered past cases and products as a possible upgrade option. The Graph based Knowledge Visualization functionality let users to explore more information about the nodes, as shown in the picture below, by clicking on "Expand Node" button. This button can be accessed by clicking on the node.

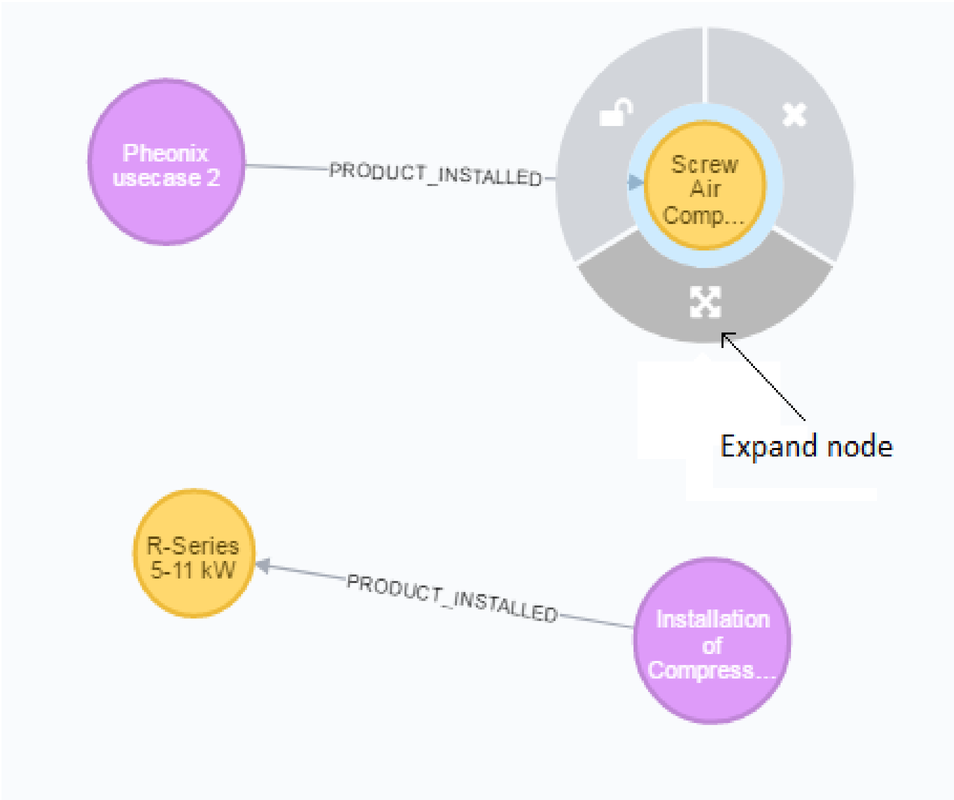

Figure 8.8 - List of Upgrade Options to Meet Given Energy Requirements

The expand node functionality lets user discover other relevant information about the node. In this case, the user can discover supplier information who supply the product, other past cases where this product was installed and most importantly information about the newer model of this product (see picture below).

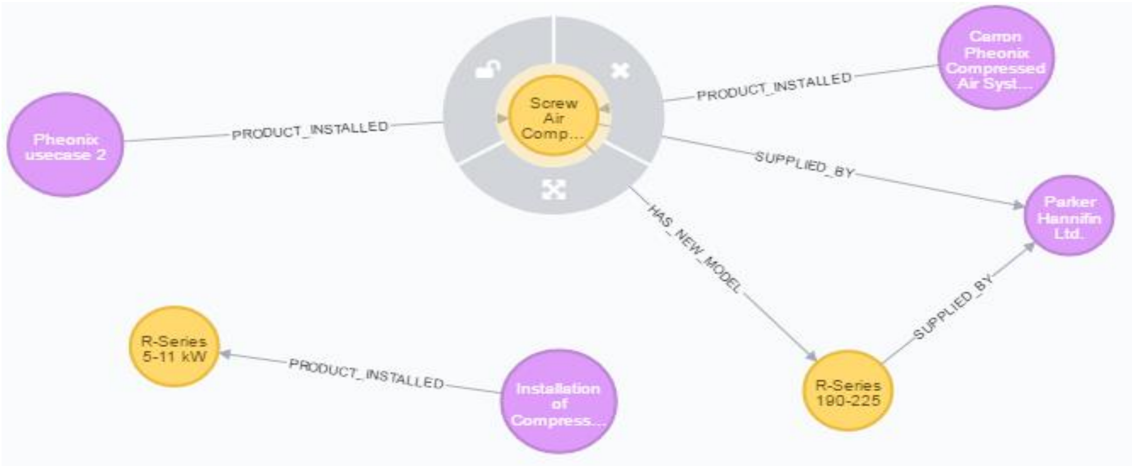

Figure 8.9 - Knowledge Chain Visualisation Example 1

Similarly, by expanding Past Case node, one can discover information about case requirements, principle and practices followed, and project details as shown in the following picture.

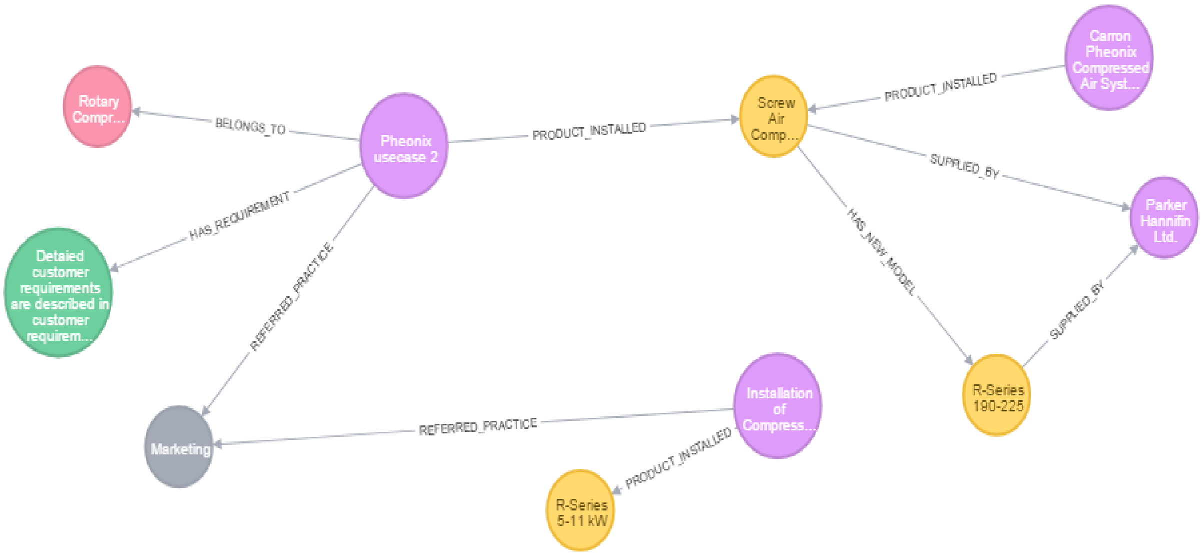

Figure 8.10 - Knowledge Chain Visualisation Example 2

The functionality to discover and visualise additional information has tremendous advantages. It facilitates organisation to create an environment where employees can discover and learn from past knowledge and thus helps to promote learning in the organisation.

8.3 System Validation with Participating SMEs

The laboratory validation results have shown that the system can be a great asset for organisations to store, represent, extract and visualise information and knowledge and use it to support innovation activities. The results have also shown system capability to promote learning in the organisation by offering users a choice to look at relevant information before presenting their ideas. This approach not only creates a learning culture but also reduces waste from ideation phase by stopping ideas that are not aligned to company's goals, or not well thought through, to enter the evaluation phase. Such ideas can then either be corrected or rejected at the initial phase of innovation process and stops management time to be wasted.

In order to examine system feasibility in real industrial environment, the system was tested with the end users. Considering the proposed system is an early proof of concept, the idea was to get general feedback from the end users. A system demonstration was prepared that was followed by interviews. The system demonstration was designed for selected business processes and the interviews questions were prepared to gather objective evidence that proposed framework and tool are fit for end users' knowledge storage and utilisation requirements.

8.3.1 Validation Objectives

This second layer of validation is designed to inspect whether the proposed framework and tool is fit for purpose as well as understand any limitations by piloting it at the end users. Therefore, the validation process doesn't cover physical installation of system at the end premises and performing live experiments. This is also due to the time constraints as the design activities at the participating company take between 8 – 12 months.

Thus, the key validation objectives are to:

- Demonstrate knowledge storage, representation and visualisation capabilities.
- Validate whether the proposed tool can be useful to systemise and manage the knowledge required to support innovation processes in the organisation.
- Test system capability to promote organisation learning by facilitating learning activities of new/existing employees.
- Explore new areas/processes where the system can be applied/used within the organisation.

A series of demonstrations and interviews are carried out to achieve above mentioned objectives. These are described in detail in the sections below.

8.3.2 System Validation at MBAS

The company is currently using ExtremeFactories Innovation Platform to manage ideas from its employees and suppliers. This system provides excellent means for idea collection, prioritisation and implementation; however, there is no option for employees to look for past cases, rules and regulations relevant to their ideas. The employees spend lot of time searching for this information. On the top, passing knowledge from experienced personnel to new employees is a big challenge for the organisation.

The proposed framework and toolkit is expected to solve above mentioned problems. In order to validate the system feasibility and capability, the System Design and Specification Process was selected as it closely matched with the research objectives. A system demonstration was designed, and the required test data was fed into the system to simulate the design process. The validation process started with brief overview of the research, proposed knowledge-based innovation framework and system demonstration of knowledge storage and visualisation tool. The demonstration covered system capability to:

- Provide the engineers access to past implemented solutions for given cost and annual energy consumption.
- List out possible upgrade options for given energy requirements.
- Generate recommendations about relevant information such principles and practices slides, past cases, business processes models etc. so the user can look at them before presenting their ideas. **->** *promoting learning in the organisation.*

The demonstration activity is followed by semi-structured interviews. The participants were asked several questions and their responses are discussed in the following sections.

Questions to verify system practicability within manufacturing SMEs' work environment.

The participants were asked to express their views about proposed system and its potential use within their organisation based on the demo that was presented to them. In general, all the participants found the system very useful to support their daily activities. Some of the feedbacks received from participants have been quoted below:

"The tool looks very practical for day-to-day uses in the company"

The users also compared the proposed system with their existing methods and approaches for knowledge storage and representation. One of the participants stated that:

"The graphical representation of information is very useful compare to information presented in spreadsheet or tabular format."

Usually for new technologies and approaches, the users are found to be resistant towards adopting them in their daily activities. However, this was not the case with the participants of this research. One of the participants stated:

"The biggest advantages I can see that the tool works on the top of existing technologies. The tool is not replacing existing methods/tools instead it complements them. The company can carry on using their existing tools/methods. The tool allows the company to gradually systematise its existing process."

Questions to validate system feasibility to manage knowledge storage and utilisation processes of manufacturing SMEs

The current knowledge storage and utilisation practices, as described in Chapter 4, are found not to be adequate. Most of the manufacturing SMEs interviewed during this research are found to be using network file storage systems and/or hard copies of past project data. These approaches make it difficult to search the stored information when required in the future. This is simply because there is no structure in place for knowledge storage. On top, the knowledge is available in different formats (e.g. .doc, .xls, ppt, .sql etc) which makes it even harder for employees to discover the relationships among these information and knowledge sources.

The proposed tool set provides a structured approach to manage different information and knowledge sources through graphical representation of knowledge using Property Graph Model. This enables the relationships among these sources to become visible. An example scenario of knowledge storage and utilisation was demonstrated to the participants. The participants pointed number of advantages of using the proposed system in their organisation. The R&D manager commented:

"The tool shows a massive opportunity for improvement compare to what we are doing to manage information related to past cases. Considering it is prototype, the tool can certainly add value to current knowledge management practices especially for managing the past cases."

The participants were asked to think about potential areas/departments/processes where the proposed system can be used in their organisation. Almost all the participants felt that the tool is very generic and can easily be customised to apply to other departments of their organisation. A senior manager commented:

"I can see we can easily apply this tool in different department e.g. Engineering, Management, Sales. For example, in Management department, one can easily learn about processes of managing a company"

Questions to test system potential to promote learning in the organisation.

When asked about whether the tool can be applied to support learning activities of new/existing employees, the participants were very confident that this tool could be very useful to train new employee. Especially when a person leaves or gets promoted, their knowledge can be accessed by a new employee. Due to simple graphical visualisation, one can easily retrieve the past knowledge from the repository.

Comparing current practice with proposed approach, senior personnel stated that:

"In current practice, if there is system design project which was implemented in past, let say 5 years ago, to find that past case one has to dig into his notes, search for Case file saved in word format on central computer. It is a very time consuming and there is also a chance that one might have lost that information. The proposed tool can eliminate these shortcomings of current practices".

The participants also stated that the tool could potentially help organisation to reduce waste in time spent to train new employees. A senior figure from the management commented:

"Tool can help in minimising the time required to teach new person. It looks very easy to retrieve information using this graph-based visualisation. We spend lot of time one-to-one basis to train a person. This tool can save 80-85% of total time spent using current practices."

8.4 Summary

The chapter has demonstrated how the conceptual framework proposed in Chapter 5 can be implemented in a real industrial environment. The outcomes of the validation activities have contributed more knowledge about validation results and proved that combination of

Innovation, Knowledge Management and Learning Organisation can enhance innovation effectiveness.

The developed Knowledge Storage and Utilisation tool has been validated in the laboratory and using case study from participating manufacturing SME. The validation results have shown that the proposed system has potential to support innovation processes by enabling innovation team to store and explore past cases, principles and practices, information about regulations and relationships among information and knowledge sources. The system is also found to useful to reduce waste from the training process. In current practices, the companies are spending lot of time on knowledge gathering and defining relationships among these sources. The Knowledge Representation functionality enables SMEs to store the knowledge in a structured way so relationships among different information and knowledge sources become visible. It makes the knowledge extraction quick and easy. Thus, the proposed system can save significant amount of time when training new employees.

The experiments results of Knowledge Extraction and Visualisation functionality have shown system capability to promote learning in the organisation. It presents users relevant information related to their queries and offers them choice to explore the semantically connected information and knowledge sources.

CHAPTER 9 - CONCLUSION AND FUTURE WORK

9.1 Introduction

The aim of this chapter is to summarise the key findings of the research and its original contribution to the existing knowledge in this research area. The research implications are described, and conclusions are drawn from the research as a whole. This chapter also provides guidance and recommendations on areas identified for further research.

9.2 Research Findings

Knowledge is considered as a valuable asset for any organisation to compete in the economic playground. By keeping this in mind, this research was commissioned to identify how this [knowledge] could be used within manufacturing SMEs to support innovation processes. The research aim was:

To create and evaluate an innovation framework incorporating novel knowledge repository to support innovation processes in manufacturing SMEs.

In order to achieve this aim and develop a knowledge repository, the research objectives were classified into high level and low level objectives. The high level objectives were:

1. Investigate the design and development of a novel Central Knowledge Repository (CKR) for the products and processes of SMEs and associated New Product Development Tools (NPDTs) to enable rapid and cost effective new products, services and processes introduction.

2. Develop an innovation framework for enabling manufacturing-based SMEs to use the CKR & NPDTs to improve new product development competences that allow manufacturing operations to become flexible and more efficient.

The above objectives were achieved by dividing them into number of low level objectives. These were:

1. Investigate what SMEs understand by innovation and the general views associated with it by focusing on manufacturing sector *(High level Objective 1).*
2. Investigate challenges, unique requirements, characteristics and current innovation practices across manufacturing SMEs *(High level Objective 1).*
3. Examine and evaluate current knowledge storage and utilisation practices and tools utilised in innovation processes in manufacturing SMEs *(High level Objective 1).*
4. Produce a Knowledge Based Innovation framework that could be applied to drive innovation in manufacturing SMEs and evaluate its impact to support innovation processes *(High level Objective 2).*
5. Design and development of the proof of concept to demonstrate how the proposed framework can be applied in practice *(High level Objective 1 and 2).*
6. Validate the system prototype by publishing the results within participating SMEs *(High level Objective 1 and 2).*

All the above objectives have been achieved during this research programme. The research findings related these objectives are explained in the following section.

9.2.1 Objective 1

"Objective 1: Investigate what SMEs understand by "innovation" and the general views associated with it by focusing on SMEs within the manufacturing sector".

This objective was aimed to review the general definition of innovation and existing innovation models; and specifically understand what constitutes innovation and innovation processes in manufacturing SMEs. The objective was achieved by undertaking three activities. The first two were planned to:

- Carry out a critical literature review to examine and evaluate the definition of innovation and models proposed by researchers and practitioners in this field. This activity will identify the meaning of innovation from the SMEs' perspective and will discover processes that are thought to support innovation in manufacturing SMEs.

- Conduct a literature review of related management approaches that are believed to enhance the innovation capacity of the organisation; and evaluate their viability to support innovation processes in manufacturing SMEs.

In the initial stage of research, an extensive literature review was carried out which formed the bulk of Chapter 2 and Chapter 4 . Literature on innovation has created a plethora of definitions. This research has fully subscribed the Innovation definition proposed by Dr. Paul Trott, who defined it as *"the management of all the activities involved in the process of idea generation, technology development, manufacturing and marketing of a new (or improved) product or manufacturing process or equipment"* [P. Trott, 2008]. This research has moved further and added the *"problem identification" and "problem solving"* as components of inception process, and incorporated *"learning organisation"* as a core part of the innovation process.

The third task was to:

- Conduct a preliminary survey to determine current processes, procedures to encourage innovation; and practices for storing documents used in the innovation processes in manufacturing SMEs.

The results from the literature review were successfully applied in the design and development of a preliminary survey to achieve above mentioned task. The outputs of this task were included in Chapter 4 which describes what constitute innovation and innovation processes in the manufacturing SMEs.

9.2.2 Objective 2

"Investigate challenges, unique requirements, characteristics and current innovation practices across manufacturing SMEs".

The second objective was to examine challenges faced by manufacturing SMEs in the innovation processes and their unique requirements as well as characteristics. The objective was accomplished by undertaking four activities. The first task was to:

- Conduct a review of the academic and practitioner's literature to identify key challenges, unique requirements and characteristics of manufacturing SMEs. This will form a list of requirements with a view to use them to develop a specially tailored Innovation framework for manufacturing SMEs.

The findings of above task are presented in Chapter 2 and Chapter 4. This research has noted that the majority of existing innovation methods and approaches were originally developed for large organisations. Therefore, they don't meet the unique requirements of SMEs such as limited resources, less defined company strategy, no dedicated product manager etc. This is a research gap that needs more attention from academics and practitioners of this field. The results of this activity contributed in defining the requirements for the design of the proposed framework.

The second task was to:

- Conduct detailed case studies to identify strengths, weaknesses and gaps in the existing innovation practices applied in manufacturing SMEs.

This task was achieved by carrying out detailed case studies and interviews with employees, and conducting industrial visits of participating organisations. The results of these activities were qualitative in nature and provided greater understanding of the problems and opportunities to support innovation processes in manufacturing SMEs.

The third task was to:

- Compare the innovation practices of participating manufacturing SMEs with the literature concerning innovation in SMEs and clarify how it differs from the practices applied by large organisations.

The results from previous two tasks were compared to analyse potential differences in innovation practices of SMEs reported in the literature with participating SMEs. This research has highlighted the potential difference in innovation practices at large organisation and SMEs. The findings are reported in Chapter 4.

The fourth task was to:

- Produce an innovation process map that reflects how the innovation processes work within manufacturing SMEs based upon identified actors, inputs, outputs and activities of the innovation processes.

This task was successfully achieved in Chapter 5, with inputs from activities undertaken as a part of Objective 1 and 2. The findings of this task have shown that innovation is a collective activity in manufacturing SMEs. In the current literature related to innovation in SMEs, the owner has been labelled as the sole innovator in the organisation. This analysis of the innovation processes of the participating SMEs has shown that the innovative idea can come from anywhere in the extended organisation including employees, suppliers, customers and external consultants.

9.2.3 Objective 3

"Examine and evaluate the current knowledge storage and utilisation practices and tools utilised in the innovation processes in manufacturing SMEs".

The third objective was to identify knowledge storage and utilisation practices applied by manufacturing SMEs with a view to identify strengths, weaknesses and gaps in existing practices. The objective was attained by undertaking three activities. The first and second tasks were to:

- Conduct a literature review to examine the knowledge storage and utilisation practices in use within manufacturing SMEs.

- Further examination of identified innovation processes, from Objective 1, to identify and evaluate the knowledge storage and utilisation practices of manufacturing SMEs.

This first task was achieved by a thorough review of existing literature on knowledge storage practices applied in manufacturing SMEs, interviews with employees and observations during industrial visits of participating organisations. The findings of this research are reported in Chapter 4. This task has highlighted several strengths, weaknesses and gaps in existing practices within manufacturing sector and provided academics and practitioners in knowledge management filed a greater understanding of sector specific problems and opportunities in this research domain.

The second task provided further insights by examination of knowledge storage practices applied in identified innovation processes in participating companies. This has helped to clarify and compare practices reported in literature with participating organisations.

The third task was to:

- Interview actors involved in the innovation process to identify the existing tools, information and knowledge sources that are being used in the innovation process; and find out potential tools and knowledge sources that could also support the innovation process.

This task was accomplished by conducting interviews with participating SMEs with a view to identify tools and information and knowledge sources used in the innovation activities. The results of this activity helped in the requirement specifications for the intended knowledge repository.

9.2.4 Objective 4

"Produce a Knowledge Based Innovation framework that could be applied to drive innovation in manufacturing SMEs and evaluate its impact to support innovation processes".

The fourth objective was to produce knowledge-based innovation framework with inputs from previous objectives. The objective was achieved by undertaking three activities. The first task was to:

- Extend the ExtremeFactories Innovation methodology by integrating knowledge management process with an aim to develop a novel combinatorial framework that will offer a knowledge-based approach to manage innovation processes in manufacturing SMEs.

The research has extended the Innovation Management methodology proposed by the EU funded ExtremeFactories project by integrating knowledge management process to support the innovation activities in manufacturing SMEs. A combinatorial approach to innovation is a new addition to existing methods in Innovation Management literature for manufacturing SMEs. This novel knowledge-based approach for innovation offers the potential to systematize the innovation and knowledge management processes and enhance the innovation capacity of the organisation. The key research findings from this task are presented in Chapter 5.

The second task was:

- Modelling the innovation process of the selected manufacturing SME to produce a model for the Knowledge Storage and Utilisation service; and identify the database schema and information sources that are being used in the innovation process.

This task was successfully accomplished in Chapter 6 by applying CommonKADS methodology to model the innovation process. The results of this activity provided insights into knowledge bottlenecks, information and knowledge requirements, available information and knowledge assets, and actor involved in the innovation process.

The third task was to:

- Design the CKR based on the identified database schema from activity 2 of this objective; and the information and knowledge sources discovered in Objective 3.

Based on the inputs from the aforementioned tasks, this stage was achieved in Chapter 6. As a result of this activity, an Entity Relationship Model was developed from the identified requirements and knowledge assets from the innovation process. These results were later used in the design and development of knowledge toolset.

9.2.5 Objective 5

"Design and development of the proof of concept to demonstrate how the proposed framework can be applied in a real industrial environment."

The fifth objective was to implement a system prototype to demonstrate how the proposed knowledge-based innovation framework would work in practice. The objective was accomplished by undertaking three activities. The first task was to:

- Examine potential software development tools for the implementation of the Knowledge Storage and Utilisation services that could be used to support innovation in the manufacturing SMEs.

This task has covered the review of potential tools, in Chapter 7 that could be used to manage knowledge in the organisation. Finally, the most appropriate tool was selected based on the requirements identified in Chapter 4, Chapter 5 and Chapter 6.

The second task was:

- Implementation of the system prototype for the Knowledge Storage and Utilisation services that could be used to support learning and drive innovation within manufacturing SMEs.

This task was completed as described in Chapter 7, using development tools and technologies identified in activity 1. This task has helped to demonstrate the implementation of a theoretical principle and showed how it can be applied in practice.

The third task was to:

- Develop a Knowledge Repository based on the identified schema in Objective 4 and populate it with the information and knowledge sources previously identified in Objective 4.

This task was achieved in Chapter 7, using Property Graph Model powered by Neo4j. One of the biggest challenges of this task was to address the issues, identified in Objective 4, with information and knowledge sources which were available in different formats that make it impossible to discover relationships among these sources. This task has presented a graph-based knowledge representation approach to address this issue. The results of this activity have described in Chapter 7. This has enabled academics and practitioners in the knowledge management field to apply the research findings when addressing problems in their work related to knowledge representation.

9.2.6 Objective 6

"Validate the system prototype by publishing the results within the participating SMEs".

The last objective was to undertake system validation of the developed toolset and discusses results of system piloting in participating organisations. The objective was accomplished by undertaking three activities.

- Carry out a laboratory-based system testing for the initial validation of the proposed proof of concept using data collected from the participating organisations.

- Conduct a series of interviews with employees of participating SMEs to seek their views on the system's practicability to support the innovation processes.

- Publish research results in academic conferences/events to get feedback and promote discussions.

These tasks were completed and described in detail in Chapter 8 . The research programme has implemented the framework proposed in Chapter 5 and developed a software tool powered with knowledge repository thus making ideas tangible; and has demonstrated how this works in practice. The results from testing and validation activities, as described in Chapter 8, have made original contributions to existing knowledge in the area of research.

Additionally, the research has proposed a novel way to the improve idea generation process by adding knowledge element into it. The proposed repository stores information about engineering, design and manufacturing principles and practices; company's product(s), and support tools to enable the next generation of the company's product(s) /process(es)/service(s) to be developed using the repository.

The framework has introduced a self-idea validation process as a part of idea generation phase. The self-idea validation process utilises the CKR to present information regarding principles and practices. The user has an option to go through this information. Thus, the ideas which are not in-line with related principles and practices can be corrected or rejected at the initial phase of innovation process.

The proposed approach provides a novel way for SMEs to generate new ideas using combination of simultaneous idea generation and evaluation prior to formal idea submission using internal and external sources available. Thus, the company will not only trigger innovation processes motivated by external factors, but it will naturally originate new innovative product and process ideas within the organisation. This is a novelty and an original contribution to the existing knowledge.

9.3 Overall Conclusion

In summary, the research has provided a great deal of contribution to existing knowledge in the field of innovation management. The primary aims and objectives of the research have been successfully achieved and provided new insights into innovation processes in manufacturing SMEs. The research work described in Chapter 5, contributes in the philosophy of systematic management of innovation by combining an innovation process, KM process, knowledge repository, methods and tools all together put into one holistic framework. The proposed innovation framework, presented in Chapter 5 would support companies to systematically manage their innovation processes and set up the concept of learning organisation where individuals can learn about a firm's best practices and procedures.

The literature review highlighted that all the previous research studies in this area lack an integrated perspective of Innovation process management. They have discussed how to improve the fuzzy front end of innovation, accelerate innovation ideas to market but underestimated the importance of building a holistic model to manage innovation and implementing the concept of learning organisation. Hence, they have been unable to provide the basis for a holistic, practical, fully integrated innovation process considering special requirements of manufacturing SMEs. Innovation management needs to be addressed from the point of view of manufacturing SMEs' characteristics and special requirements. Existing innovation management frameworks are limited in terms of the integration of creative tools in the innovation processes and the integration of required knowledge for creating an environment to foster the Learning Organisation concept.

The need for such a holistic approach to systematically manage innovation processes and implementing the concept of learning organisation by providing a flexible innovation management environment with well-defined innovation stages/processes, creativity tools and central knowledge repository proved to be a necessity. Hence, this statement addresses the key question about the rationale for the investigation in developing an innovation platform. Since innovation is a non-linear process, a concurrent innovation platform can be a valuable tool for manufacturing SMEs to survive and compete in this hyper-competitive economic playground.

9.4 Research Limitations

Although the research has made novel contributions to existing knowledge by developing a knowledge-based approach for innovation and modelling SME's innovation process, there are still a few limitations. The main limitation is the implementation of the knowledge-based innovation framework in only one organisation. Having pilot studies established in more organisations could have provided a clearer indication on the viability of the proposed framework and toolset. However, this limitation would have been overcome by sufficient time. The employees of Centre for Factories of the Future Ltd, where the researcher is working full time, will continue to build the proposed system and will implement it at potential customers' sites.

The total number of participants and companies who were involved in the interviews was also a limiting factor. The primary reason for this was to limit the research scope to a manageable level and also due to limited access to manufacturing SMEs, with companies being too busy with their work and having limited/no resources to support research activities without any potential benefits in near future. A large employee sample with greater access and sufficient time would have enabled further insights into innovation and knowledge management practices in their organisations and could also have highlighted potential differences within SMEs in manufacturing sector.

The qualitative research has been criticised due to its subjective nature and this could also raise a concern in this research. However, as discussed earlier in Chapter 3, the qualitative methodology has also provided a benefit to enhance the level of detail in the collected data, which provided opportunities to glean insights during the analysis process. This may not be possible with purely quantitative research. The subjective limitation was overcome by having the results validated from the participants. For example, the research objectives were validated by presenting and getting approval from participating manufacturing SMEs in the ExtremeFactories project. The data collected from interviews was sent back to participants to review and provide approval.

9.5 Recommendations for Future Work

The literature review has revealed a significant research gap between large organisations and SMEs. Most publications in the literature are about solving business issues in large organisations and only few examples are found dealing with issues related to SMEs. This research programme has provided a great deal of contribution to the existing knowledge to address this issue. However, more efforts are required to support SMEs in their daily activities. Here are some areas identified during this research for further investigations:

- Further implementation and integration of the proposed knowledge-based approach to innovation platform and evaluating its success in supporting innovation processes and enhancing innovation capacity of the SMEs. The results of validation activities have shown that the proposed framework will have positive impact on the SMEs' innovation process. However, the further investigation by practically implementing and testing the framework within more SMEs will discover potential culture issues that can hamper its use.

- Investigating the viability of the proposed knowledge-based innovation approach within SMEs in other sectors and examine their differences and special requirements. It is expected the majority of the components will remain same. The only difference will be in information and knowledge sources in use in the innovation processes. The proposed knowledge representation methods are flexible enough to accommodate such differences.
- The heterogeneity within companies classified as SMEs needs to be considered, as practices in small firms may differs with one in use in medium-sized firms. This also applies to companies in different industries. Responses generated during the research dissemination activities started interesting discussions regarding viability of the proposed framework and the CKR in companies with different sizes. As per the EU definition, the companies from 10 to 249 employees are classified as a SME. Therefore, research to investigate the applicability of the proposed framework with different sized SMEs is worthy of further research.
- The proposed framework and knowledge toolset has been tested using real dataset from MBAS's System design and implementation process. Further validation can be carried out using different innovation processes to evaluate effectiveness and shortcoming of the proposed system.

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APPENDIX A - QUESTIONNAIRE

What is the total number of employees in the company?

Mark only one oval.

- <10
- <50
- <250
- >250

What is the approximate annual turnover of the company?

Mark only one oval.

- <= 2m euros
- <=10m euros
- <=50m euros
- >50m euros

What does your company produce/supply?

Mark only one oval.

- Products
- Service
- Both

What does your company understand by Knowledge Management?

Mark only one oval.

- Never heard of it
- Something they are doing but not under same name
- It is a strategic part of the business
- Other:

What do you think about existing policies and procedures of knowledge management in your organisation?

Mark only one oval.

- It is very important, relevant and latest
- It is very important, relevant but not updated regularly

- ○ It is just trivial, a part of formalities and of no use.
- ○ Other:

Is there a written knowledge Management policy or strategy in your organisation?

Mark only one oval.

- ○ Yes
- ○ NO
- ○ Don't Know

What tool do you use to store information and knowledge?

Tick all that apply.

- ▢ Employee computer as documents e.g. word, excel, PowerPoint, design file formats etc
- ▢ Central server
- ▢ Email
- ▢ On Papers
- ▢ Company Wiki page
- ▢ Knowledge Management Software
- ▢ Data warehousing
- ▢ Document Management System
- ▢ Other:

What tool would you prefer for information and knowledge storage?

Mark only one oval.

- ○ Connected Data Technologies
- ○ Internet applications like Wiki Page
- ○ Document Management System
- ○ Other:

What are the factors that hamper knowledge storage and utilisation in your organisation?

Tick all that apply.

- ▢ Lack of technological knowhow
- ▢ Existing systems doesn't fit my organisation's needs

- ▢ Existing systems too expensive
- ▢ Information overload
- ▢ Poor sharing of knowledge in the organisation
- ▢ Other:

Have you faced any issues when retrieving/accessing required information and knowledge for innovation activities from the mentioned resources?

Tick all that apply.

- ▢ Never faced any issues.
- ▢ Take too long to find information
- ▢ Sometime cannot find the information
- ▢ Information stored in different systems makes it hard to find all the needed information.
- ▢ System too complicated.
- ▢ Other:

What are barriers for effective implementation of Knowledge storage and sharing strategy in your organisation?

Tick all that apply.

- ▢ Changing people behaviour from knowledge hoarding to sharing
- ▢ Determining what kind of knowledge to be managed and make it available
- ▢ Lack of top management commitment
- ▢ Overcoming technological limitations
- ▢ Lack of understanding of KM and its benefits
- ▢ Justifying the use of scarce resources for KM
- ▢ Other:

What information and knowledge sources are used in the innovation processes?

Tick all that apply.

- ▢ Past cases
- ▢ Design Databases
- ▢ Requirements documents
- ▢ Rules and regulations documents
- ▢ Journals

- ▢ Blogs
- ▢ Patents databases
- ▢ Supplier product/service databases
- ▢ Competitor websites
- ▢ Information about current systems/product in use at customer’s organisation
- ▢ Other:

What format the information and knowledge sources are available in?

Tick all that apply.

- ▢ Word file format (.doc)
- ▢ Excel File format (.xls)
- ▢ PowerPoint file format (.ppt)
- ▢ Design file format (.cad)
- ▢ Picture file format (.jpeg)
- ▢ Video file format (.mp4)
- ▢ Paper format
- ▢ Database format (e.g. .sql)
- ▢ In Employee minds
- ▢ Other:

What are your views of using Central Knowledge Repository to support innovation processes in the organisation.

Mark only one oval.

	1	2	3	4	5	
Strongly Disagree	⬭	⬭	⬭	⬭	⬭	Strongly Agree

At which level of the organisation it is most suitable to implement a knowledge management strategy?

Mark only one oval.

- ○ Company wide
- ○ Department level
- ○ Process Level

- At all levels

Consent Form

I have read the information presented in the information letter about the study "An Investigation into Design and Development of Innovation Platforms for Application in Manufacturing companies" I have had the opportunity to ask any questions related to this study, and received satisfactory answers to my questions, and any additional details I wanted. I am also aware that excerpts from the survey may be included in publications to come from this research. Quotations will be kept anonymous. I understand that relevant sections of the data collected during the study may be looked at by individuals from De Montfort University, from regulatory authorities, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my responses.

*

Tick all that apply.

- With full knowledge of all foregoing, I agree to participate in this study.
- I agree to being contacted again by the researchers if my responses give rise to interesting findings or cross references.

Your name: *

Company name: *

Position: *

Email:

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Google Forms

Screen reader support enabled.

APPENDIX B - LINKEDIN POST CONTENT

How can we boost innovation capacity of the manufacturing companies?

In this hyper-competitive economic environment, it is essential for the manufacturing companies to try out new and effective ways to produce innovative products and/or services for their customers. Number of initiatives have been taken by academic world to support Small and Medium Sized Enterprises (SMEs) in order to systematising their innovation processes.

I am currently working on similar initiative which is jointly supported by Centre for Factories of the Future Ltd, UK and De Montfort University, UK. In order to support our research work, a short survey of maximum 10 minutes has been produced.

I will request to all the members representing manufacturing companies in this group to allow your 10 minutes of busy schedule to fill this survey. As a token of appreciation, a copy of survey findings will be sent to you.

Here is a link to the Survey: https://goo.gl/27GF8g (Either click on the link or copy and paste it into your browser to access the survey)

APPENDIX C - ARTICLE AT GREATER BIRMINGHAM CHAMBERS OF COMMERCE

From: Charles, Paula [mailto:P.Charles@birmingham-chamber.com]
Sent: 22 May 2015 15:17
To: 'Lakhvir Singh'
Subject: Survey

Hi Lakhvir

I am well thank you. I break up today for two weeks! If you need any help during this time, my colleagues Sandra and Jeanette will be happy to help

We tweeted May 12th and the article was in e-news:

Brum Chamber M'Ship@brummembership May 12
Could you assist a new Member @C4FF_UK in completing the survey? http://www.birmingham-chamber.com/BCCG/Enews/ViewArticle.aspx?NewsID=1257&StoryID=5 …
(102 impressions and 1 engagement)

It also went into the weekly update (see below)

The stats are:
Article: Could you assist a new Member in completing the survey – 12 clicks

Stats on Totals:

Sent: 32917
Opens: 3829
Clicks: 291

Kind regards
Paula

From: Greater Birmingham Chambers of Commerce [mailto:weeklyenews@chambernews.info]
Sent: 12 May 2015 14:24
To: Charles, Paula
Subject: Weekly Update

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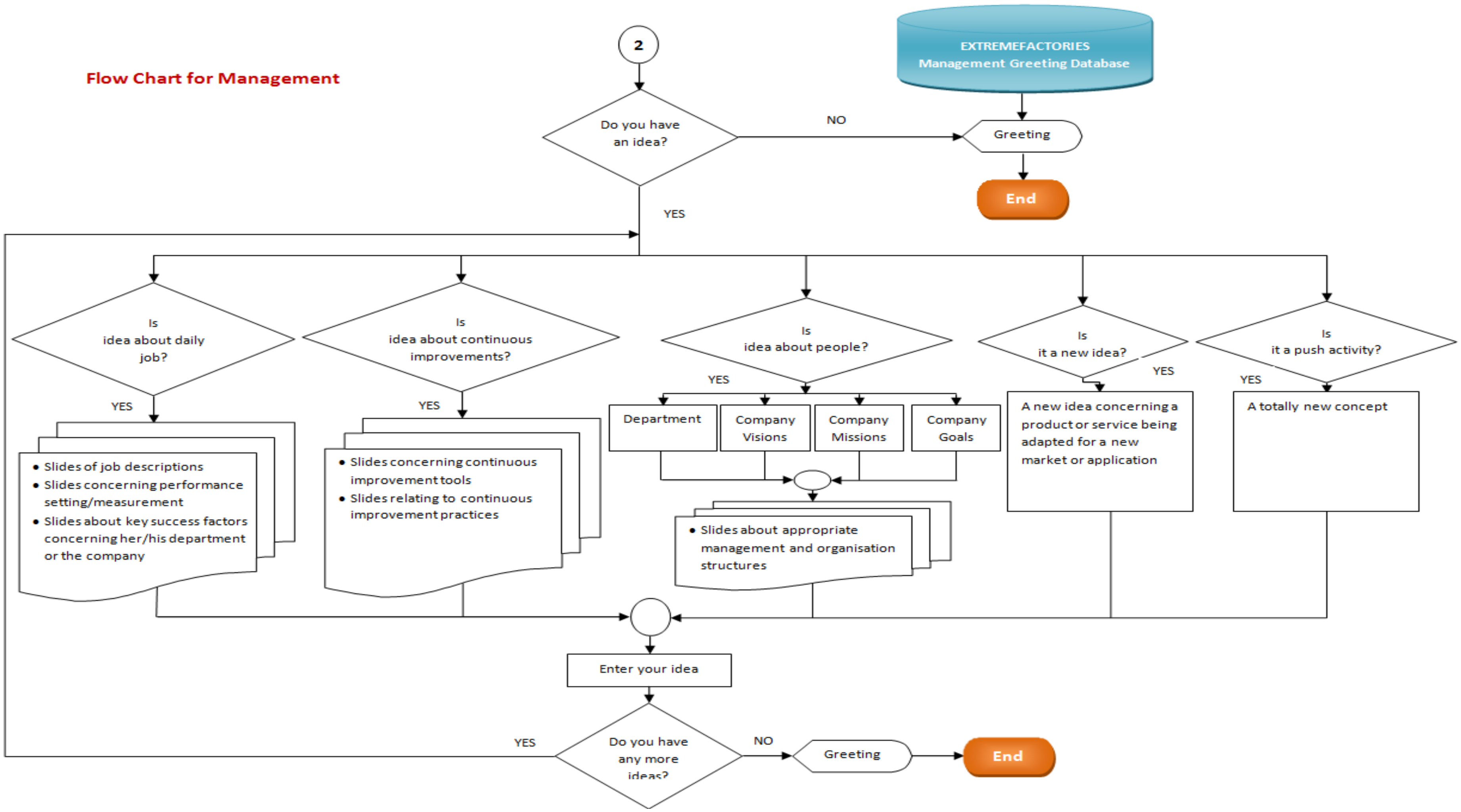
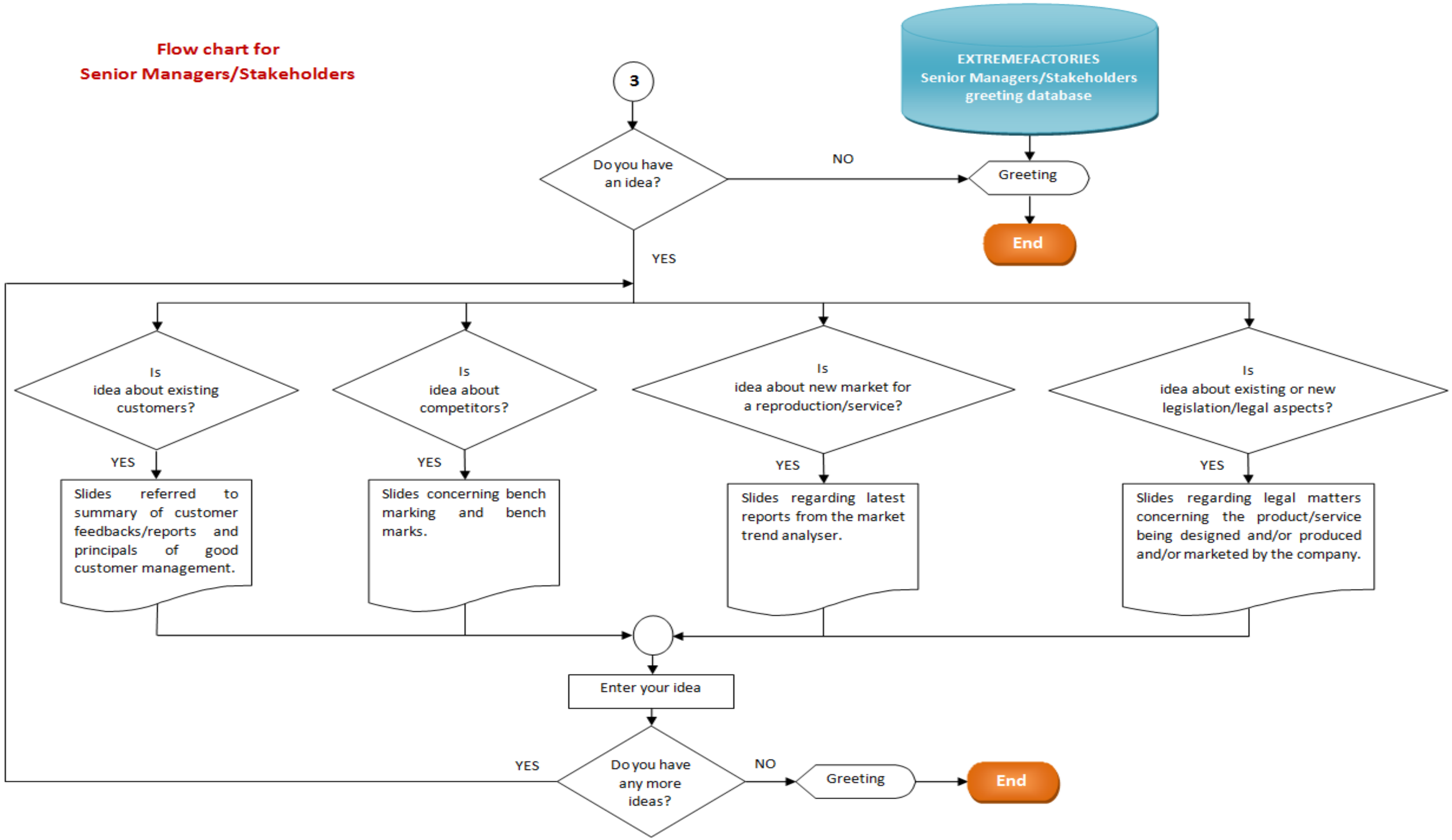
APPENDIX D - FLOW CHART FOR MANAGEMENT



APPENDIX E - FLOW CHART FOR MANAGERS/STAKEHOLDERS



APPENDIX F - CASE STUDIES

This section list the brief summaries of 5 case studies that were studied in this research. These case studies were taken from the Case Study database available at C4FF. The full text of these case studies is available on the ExtremeFactories Project website .

F.1 Case 1 – FAMMSA

FAMMSA is a family owned company founded in 1977 in Los Yébenes (Toledo), manufacturing different lines of products for the electrical power industry, mainly: metallic supports for power lines up to 400Kw, metallic structures for electrical substations, bases for distribution and power transformers and solar trackers.

FAMMSA's main process is the manufacturing of metal-works for electrical distribution. There are many important sub-processes such as the Management of Requests from Customers, Management and Presentation of Tenders, Logistics and Inspections of material and finished product.

The company does not have any formal process to carry out Innovation. Identification of opportunities for innovation and development of innovation projects mainly rely on the Quality and Engineering department.

FAMMSA manufactures a type of product with high restrictions imposed by the customer but also by the national, European and International regulations. In this sense FAMMSA does not innovate in product or design since the specifications of the product are always closed. Anyhow FAMMSA believes that there're many areas of the company where they can innovate in order to increase the quality of the products or to improve the efficiency of the company's processes (e.g. reduction of the time to deliver a specific order, reduction of paperwork in QM, reduction of response time of a maintenance or support request, etc.).

FAMMSA does not identify Innovation as a process of the company, since it's not present in its quality manual and there is not a methodological or procedural way to tackle it. Anyhow FAMMSA is constantly launching innovation projects related to the improvement of their manufacturing, maintenance and quality processes as part of their weekly routine. FAMMSA schedules a weekly Brain-Storming session involving the main departments of the company i.e. Commercial, Administration & Finance, Manufacturing and Quality. Manufacturing staff, suppliers or customers are not directly involved in this session, but their requests recommendations have been previously gathered by the participants in stand-up meetings or phone conversations.

The objectives of this session are:

- To identify current problems and bottlenecks in the processes.
- To propose potential solutions to the previously identified problems.
- To propose strategies for the new projects.

The problems of not systematizing these activities are:

- Part of the information generated during these sessions is lost, since these sessions are oriented to solve short term problems, nobody in the team is responsible for wrapping up the findings made in the sessions and there's not a formal follow-up stage to verify the effectiveness of the proposed ideas.
- Ideas generated in the Brain Storming process are not "collectivized", which can generate unfruitful and undesired discussions in the team. For example, introducing voting techniques would help creating collective solutions.

Anyhow, as a result of these sessions the company has managed to introduce meaningful improvements and innovations in their processes such as:

- Reduction of the time in tanks painting by mixing the coating and painting processes. The operators working in this area proposed this improvement after observation and application of the process in several projects.
- Improvement of the behaviour of the finished product and reduction of complaints by introducing laparoscopy technologies to perform the cleaning of metallic shavings in parts of the equipment that hard to find. Metallic shavings are often the cause of malfunctioning of transformers.

During this study, an assessment was carried out to assess the innovation effectiveness of the company. The assessment results are shown in the table below.

Table F.1 - Innovation Effectiveness Assessment at FAMMSA

Key Factors	**Questions for the assessment**	**Score (1 to 5)**	**Comments**
Organizational policies and practices	1. The quality and quantity of an organization's efforts to train organization's members to use new technology	2,5	+: FAMMSA has made a huge effort in the last year to train its staff: for operating new equipment, to obtain personal certificates for materials and process evaluation and foreign languages. -: No training in Innovation methods and tools.
	2. User support – the provision of technical assistance to technology users	2,5	+: Technical assistance provided at the working place by Quality department. -: No additional support to users.
	3. Rewards, such as promotions, praise from supervisors	2	-: Rewards or promotions are not a common practice
	4. Effective communication regarding the reasons for the implementation of the new technology	2	-: No tools for effective communication rather than periodical meetings
	5. The provision of time	2	-: Experimentation with new

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
	for users to experiment with the new technology		technology is not a common practice
Implementation climate	1. Employee's shared perceptions of the importance of innovation implementation within the organization	2,5	+: sound perception of the necessity for innovation in management, quality and engineering staff. -: not a uniform perception of this necessity.
Management Support	1. Does management support and promote innovation activities?	2,5	+: Management is really committed to support innovation. -: No promotion campaigns to stimulate the staff in proposing innovative ideas.
Financial Resource Availability / Accessibility	1. Does the company have financial resources available for innovation projects?	5	+: A high percentage of the incomes is invested in innovation projects
	2. Does the company know about the existence of regional, national, European or international initiatives to promote and fund innovation activities?	2,5	+: Management keeps an updated list of regional and national initiatives. -: Knowledge about international opportunities can be improved.
Learning Orientation	1. Do the teams perceive the risk of innovation projects?	1	-: No perception of risk in innovation projects.
	2. Learning attitude?	3,5	+: Proactive staff with a good learning attitude. -: Unbalanced learning attitude. Part of the staff is not keen on changes.
Managerial Patience	1. Are managers committed to the long-term results of the innovation and understand a short-term decline of the productivity during its implementation?	4	+/-: Management is expecting to obtain mid-term results, though this depends on the type of investment.
	TOTAL:	**17,2**	

The following diagram reflects the assessment performed above:

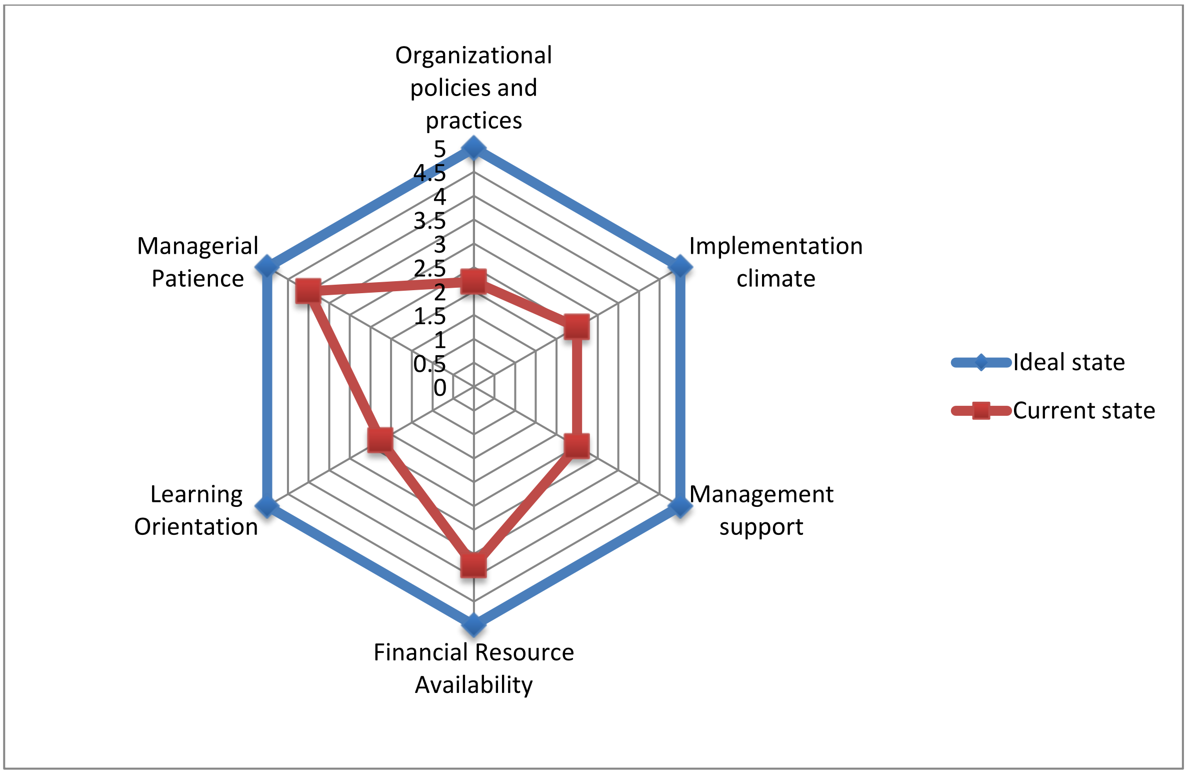


Figure F.1 - Current vs. the Targeted Situation at FAMMSA

An ideal system would be a methodology and platform that can support FAMMSA in SYSTEMATIZING its innovation process, keeping records and tracks of all the events occurred in the company during this process. In order to increase the innovation potential of the company and to improve the efficiency of the current innovation process, it will support FAMMSA in reinforcing two key aspects for success:

- Adapt the organizational practices and policies to embrace innovation processes
- Improve communication with the whole staff, suppliers and customers.

F.2 Case 2 – SAFEVIEW

SAFEVIEW is a global provider of business solutions for digital TV with more than 80 customers in Europe, Asia and Latin America. SAFEVIEW develops and integrates its own and third party products in solutions that cover the complete digital TV value-chain. The main products offered by the company are:

- CAS & DRM (SAFEVIEW®): SAFEVIEW CAS integrates the functionalities of CA (Conditional Access) and DRM (Digital Rights Manager) in a single system. It offers a high level of content protection to any type of operator disregard of its size and type of platform (IPTV, cable, satellite, terrestrial…).
- Punto Azul middleware: Value Added Services platform that opens new lines of revenue for Pay TV operators and broadcasters by enabling services like targeted and interactive advertising, fidelity programs, games synchronized with broadcasted video, betting, etc.

- SAFEVIEW Set Top Boxes (IPOXX) are designed for the ultimate home theatre experience. Our STB are designed to support highest quality HD videos on the largest HDTV. The STBs come with full support for HD videos and digital multichannel sound. The STB also allows users to view HDTV and DVD videos right from their IP network. SAFEVIEW develops STB for IPTV, Cable, Satellite and DTT.
- SAFEVIEW CRM (Customer Relationship Manager): this solution has been designed to cover the needs of pay TV operators in horizontal or vertical markets.

SAFEVIEW's main process is the off-shore manufacturing of equipment. Other important processes are Software Design and Development and Quality Assurance. The company does not have any formal process to carry Innovation. Identification of opportunities for innovation and development of innovation projects mainly rely on the role of the RTD and Innovation Manager.

SAFEVIEW designs a type of product that can be highly customised by the customer. It's also affected by the international trends of the market as well as national, European and International regulations. SAFEVIEW innovates both in product and services, being triggered by the customers or by SAFEVIEW's staff.

SAFEVIEW does not identify Innovation as a process of the company, since it is not present in its quality manual and there is not a methodological or procedural way to tackle it. Anyhow SAFEVIEW is constantly launching RTD and innovation projects for the creation of new products and services for their customers, and also to open new target markets and sectors.

The innovation process is very much dependent on the RTD manager, who proposes the most part of the innovation and RTD projects in the company. From time to time the company holds weekly Brain-Storming sessions involving the main departments of the company. However, these activity are not performed in a regular basis.

As a result of the innovation activities, the company has managed to create high technology products offering very meaningful added value functions. The products of its catalogue are an example of the outcomes of the innovation activities carried out in SAFEVIEW.

During this study, an assessment was carried out to assess the innovation effectiveness of the company. The assessment results are shown in the table below.

Table F.2 - Innovation Effectiveness Assessment at SAFEVIEW

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
Organizational policies and practices	1. The quality and quantity of an organization's efforts to train organization's members to use new technology	3	+: Training to obtain personal certificates on existing technologies, foreign languages… -: No specific training on innovation
	2. User support – the provision of technical assistance to technology users	4	+/-:Self-learning attitude.

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
	3. Rewards, such as promotions, praise from supervisors	2	-: Rewards or promotions are not a common practice
	4. Effective communication regarding the reasons for the implementation of the new technology	2	-: No tools for effective communication rather than periodical meetings
	5. The provision of time for users to experiment with the new technology	2	-: Experimentation with new technology is not a common practice
Implementation climate	1. Employee's shared perceptions of the importance of innovation implementation within the organization	2,5	+: sound perception of the necessity for innovation in management, quality and engineering staff. -: not a uniform perception of this necessity.
Management Support	1. Does management support and promote innovation activities?	2,5	+: Management is really committed to support innovation. -: No promotion campaigns to stimulate the staff in proposing innovative ideas.
Financial Resource Availability / Accessibility	1. Does the company have financial resources available for innovation projects?	4	+: A high percentage of the incomes is invested in innovation projects. +/-: Mostly regional funds.
	2. Does the company know about the existence of regional, national, European or international initiatives to promote and fund innovation activities?	3	+: SAFEVIEW has participated and participates in several regional and national projects. Nowadays they are participating in one EU project. +/-: Management knows about EU initiatives but this knowledge could be improved. -: Knowledge about funding initiatives is centered in one person of the company. This information is not updated in a repository accessible by the whole company.
Learning Orientation	1. Do the teams perceive the risk of innovation projects?	1	-: No perception of risk in innovation projects.
	2. Learning attitude?	3,5	+: Proactive staff with a good learning attitude. -: Unbalanced learning attitude. Part of the staff is not keen on

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
			changes.
Managerial Patience	1. Are managers committed to the long-term results of the innovation and understand a short-term decline of the productivity during its implementation?	4	+/-: Management is expecting to obtain mid-term results, though this depends on the type of investment.
	TOTAL:	**17,35**	

The following diagram reflects the assessment performed above:

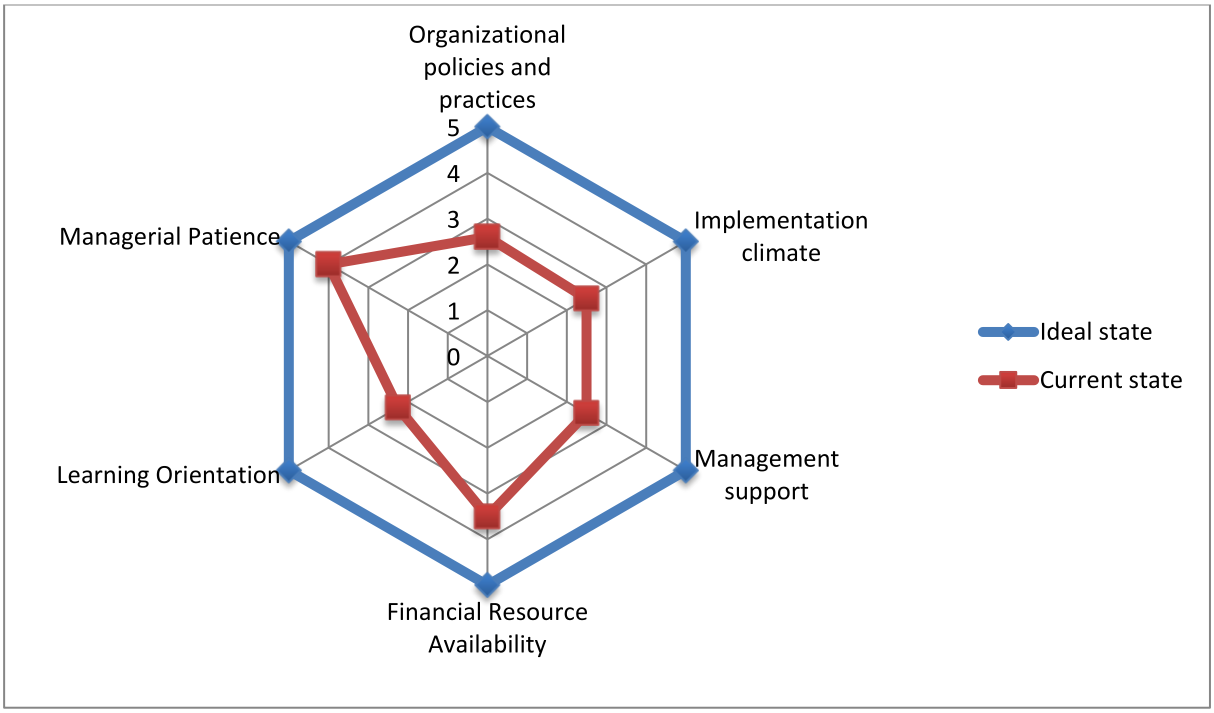


Figure F.2 - Current vs. the Targeted Situation at SAFEVIEW

An ideal system would be a methodology and platform that will support SAFEVIEW in SYSTEMATIZING its innovation process, keeping records and tracks of all the events occurred in the company during this process, and also to extend the responsibility for innovation to other actors in the company. In order to increase the innovation potential of the company and to improve the efficiency of the current innovation process, it will support SAFEVIEW in reinforcing two key aspects for success:

- Adapt the organizational practices and policies to embrace innovation processes

Improve communication with the whole staff, suppliers and customers.

F.3 Case 3 – OAS

OAS is an innovative middle-sized company with a rich experience in weighing technology and industrial plant construction all over Europe. OAS AG has been founded as a small engineering office in 1982 and ever since it expands steadily. From the beginning, the young company distinguishes itself by striving for innovation. Within the framework of a research project, the OAS founder Otto A. Schwimmbeck developed the first ever world-wide computerised self-calibrating weighing system certified for application Europe-wide by the federal certification office in Braunschweig, Germany. In the 1990's, the OAS AG grew stronger involved in foreign markets. Today, the OAS AG successfully acts world-wide and has offices and cooperation in China, Bulgaria and India.

The field of OAS activities spans planning and realisation of complete manufacturing plants of branch-specific batch-oriented manufacturing. It includes supply of measuring and automatic control systems and development of innovative software solutions for these systems. By the foundation of the OAS Automation GmbH in 2011, the division of the OAS AG which especially works in the process automation of the automotive industry, OAS entered a new market area.

The portfolio of OAS comprises a wide range of products:

- Process control technology with the process control system ***PRONTO***
- Process engineering from single aggregates to delivery of turn-key plants
- Process automation, electrical engineering and system integration
- Weighing and dosing technology: truck scales, hopper scales, weighing terminals, etc.
- Logistic process management: self-service terminals, special software application LOGIS

The table below shows the assessment of the current situation at OAS in terms of its complying with the six key factors for the implementation success.

Table F.3 - Innovation Effectiveness Assessment at OAS

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
Organizational policies and practices	1. The quality and quantity of an organization's efforts to train organization's members to use new technology	2	-: OAS approach regarding organised training is rather un-systematic. Using new technology is mainly learned ad-hoc.
	2. User support – the provision of technical assistance to technology users	4	+: Technical support to the users is at a high level.
	3. Rewards, such as promotions, praise from supervisors	1	-: Innovation in the company is seen as an everyday task. No incentives policy exists.

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
	4. Effective communication regarding the reasons for the implementation of the new technology	3	+: During the inception process reasons to implement new technology are communicated to the relevant staff members. It should be extended to a larger community
	5. The provision of time for users to experiment with the new technology	2	+ -: The users themselves have not enough time to experiment. OAS development team goes through several prototypes phases, what can be seen as experimenting.
Implementation climate	1. Employee's shared perceptions of the importance of innovation implementation within the organization	3,5	+: The shared perceptions of importance of innovation implementation within the organization are mainly kept within the project development team
Management Support	1. Does management support and promote innovation activities?	3,5	+: Management to a great extent starts the innovation activities
Financial Resource Availability / Accessibility	1. Does the company have financial resources available for innovation projects?	3	+: Company has certain funds to finance innovations, but some additional extra-company funding sources would be welcome
	2. Does the company know about the existence of regional, national, European or international initiatives to promote and fund innovation activities?	4	+: OAS participated and participates in several EU and national projects
Learning Orientation	1. Do the teams perceive the risk of innovation projects?	3	+: Both management and development teams are aware of the risk of innovation processes.
	2. Learning attitude?	4	+: Learning attitude in OAs can be evaluated positively
Managerial Patience	1. Are managers committed to the long-term results of the innovation and understand a short-term decline of the productivity during its implementation?	3,5	+: OAS mainly tries to achieve innovations in the short term. There is however full awareness of the benefits of long term innovations as well. +: Risk of short term declines in productivity with innovation projects is regularly considered and taken into account.
	TOTAL:	**23,5**	

The following diagram reflects the assessment performed above:

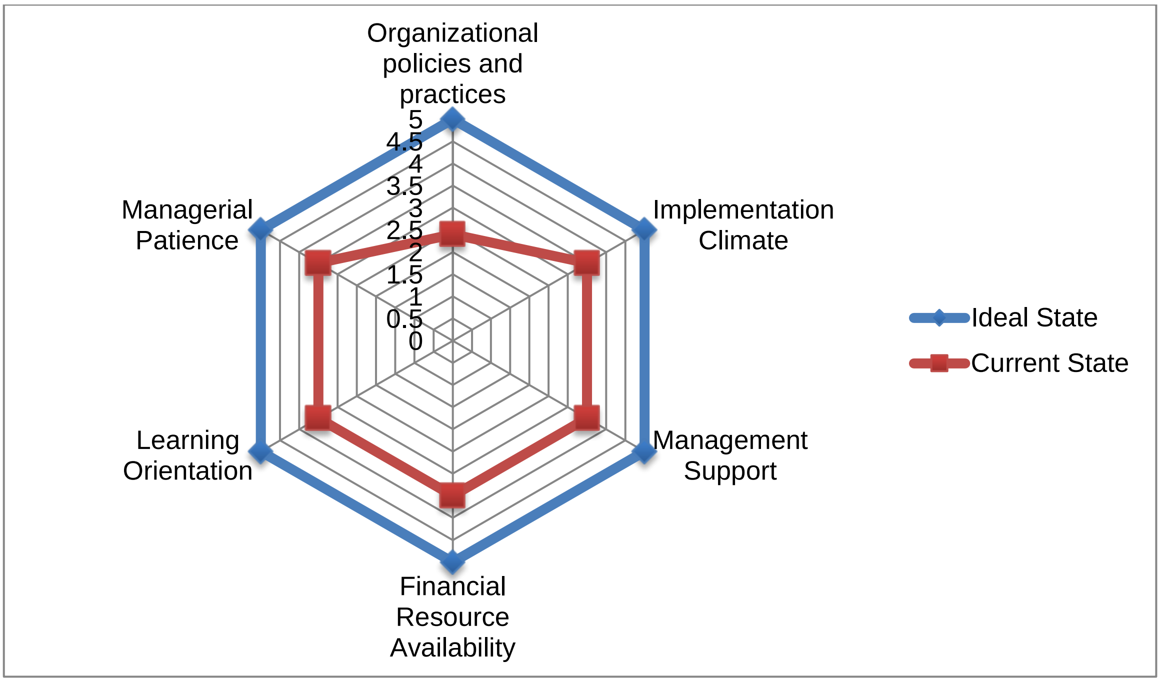


Figure F.3 - Current vs. the Targeted Situation at OAS

Although rather successful and innovative OAS shows still a large potential for improvement of innovation processes. From the analysis above diagram it is obvious that the weak point in the innovation process is in the organisational policies and practices. In addition, the other key factors for innovation leave space for improvements. Structured documentation and tracking of innovative ideas in OAS, which is currently not at a satisfactory level and can lead to a loss of ideas that are not sufficiently documented

Adaptation of organisational practices and policies to enhance innovation processes should be oriented to improving communication with the whole staff and in the network of suppliers and customer what is seen in OAS as a key aspect for success.

F.4 Case 4 – ARMBRUSTER Engineering

Armbruster Engineering GmbH & Co. KG, Bremen (AE) was founded in 1994 with working area in Automation Solutions and Manufacturing Factories design. The working area was extended to PC-based control systems, process optimisation, and ramp-up and maintenance support systems. In 2002 the ELAM system for Monitoring and Control of Assembling Processes was introduced, as a step in the company's orientation to ICT systems for manufacturing. Recently AE extended their portfolio with ICT solutions for Quality management, mobile assembly control for railway products and process visualisation.

Company activities are mainly organised around the production of the Manufacturing Execution System (MES) for manual assembly processes, which is delivered fully equipped in hardware installation and with the own developed above mentioned software ELAM. A full range of after sale services is offered to customers as well.

The causes which trigger the innovation process at AE can be classified into the groups of customers' requirements – innovation pull and technology/market trigger – innovation push. The third group of innovation causes at AE is so-called continuous innovation i.e. causes coming from the bugs fixing and "weak points" removing.

The table below shows the assessment of the current situation at AE in terms of its complying with the 6 key factors for the implementation success.

Table F.4 - Innovation Effectiveness Assessment at ARMBRUSTER Engineering

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
Organizational policies and practices	1. The quality and quantity of an organization's efforts to train organization's members to use new technology	2	-: AE has not put much effort (lack of time and lack of money) to train its stuff. This is usually done by the stuff members themselves
	2. User support – the provision of technical assistance to technology users	4	+: Technical assistance is provided whenever required
	3. Rewards, such as promotions, praise from supervisors	3	-: Rewards or promotions are not a common practice. Praising is applied by colleagues and supervisors
	4. Effective communication regarding the reasons for the implementation of the new technology	3	+: Meetings for populating software and general requirement lists are used as a form of communicating the reasons for the new technology
	5. The provision of time for users to experiment with the new technology	2	+: Generally much time is dedicated to develop and create new software parts using new technologies. This also includes testing
Implementation climate	1. Employee's shared perceptions of the importance of innovation implementation within the organization	3,5	+: There is a perception of the necessity for innovation in management and to some extent in the staff -: Perception of the necessity is not uniform
Management Support	1. Does management support and promote innovation activities?	3,5	+: Management is really committed to support innovation and sees it as absolutely mandatory

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
			-: No special undertaking for making staff members more innovative Management is often lacking time for direct support of innovation
Financial Resource Availability / Accessibility	1. Does the company have financial resources available for innovation projects?	2	-: The company has very limited resources regarding the investments of innovation projects which are not directly connected to customer needs and requirements
	2. Does the company know about the existence of regional, national, European or international initiatives to promote and fund innovation activities?	1	-: Management has no profound awareness of funding schemes for different kinds of innovations -: Knowledge about international opportunities can be improved, funding scheme repository should be installed +: AE has been involved in a national project
Learning Orientation	1. Do the teams perceive the risk of innovation projects?	2	+: Management as well as other team members are well aware that innovation for productive and manufacturing equipment is highly risky
	2. Learning attitude?	3	+: Most team members have good learning attitude and are willing to learn +: As sometimes training for new technologies misses staff members try to train themselves
Managerial Patience	1. Are managers committed to the long-term results of the innovation and understand a short-term decline of the productivity during its implementation?	4	+: Management is expecting to obtain long-term results (as it is an owner driven company) and are well aware of the decline of productivity during innovation implementations
	TOTAL:	**17,8**	

The following diagram reflects the assessment performed above:

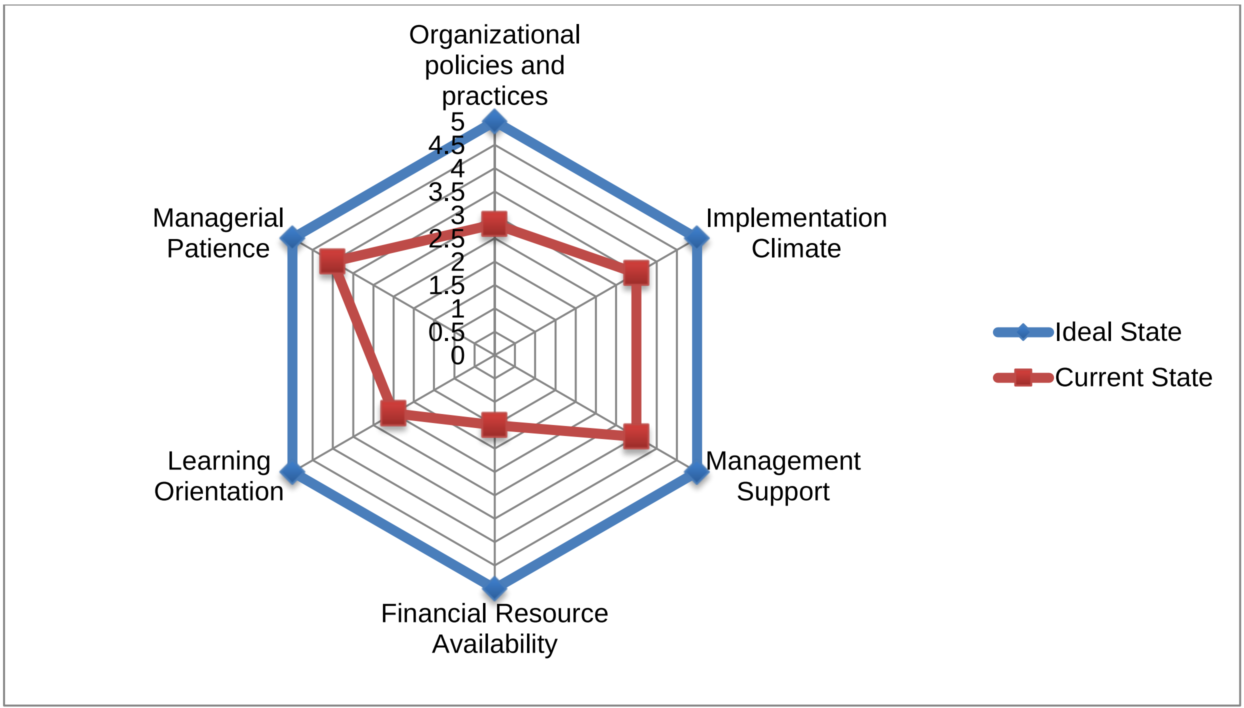


Figure F.4 - Current vs. the Targeted Situation at AE

Armbruster Engineering is very successful in keeping and extending their market position and has done several important steps in portfolio adaptation to market requirements. However, due to time and cost constraints, the innovation process management was not given a due importance. The analysis of key factors for innovation presented above allows for conclusion that the expectations from the innovation platform to be developed are rather high in AE.

The factors which require higher improvements are Financial Resources Availability and Learning Orientation. Taking care of the rather good current Managerial Patience, Management Support and Implementation Climate for the innovation process, the innovation platform is expected to significantly support enhancement of organisational policies and practices and learning orientation regarding the innovation process.

Specific improvements in efficiency of the current innovation process are expected in reinforcing the key aspects for success by:

- Adapting the organizational practices and policies to enhance innovation processes in terms of introduction of regular brain storming and similar sessions in the company.
- Improve communication with the whole staff and in the network of suppliers and customers, in order to introduce concepts of the Open Innovation approach.

F.5 Case 5 – Nikari Oy

Nikari Oy, founded in 1967, is a manufacturer of sustainable wood design products of exquisite quality. The founder - master cabinet maker, designer Kari Virtanen has worked with the greatest Finnish architects and designers such as Alvar Aalto and Kaj Franck. Through decades his determination to concentrate on wood and its ecological benefits has gained Nikari great knowledge about Finnish wood and surface treatment materials like oils, waxes and soaps.

Nikari manufactures its furniture with handicraft tradition. The company does not utilize automated computer controlled manufacturing lines. However, the furniture design is computer aided. Readiness to use any online and mobile communication tools exists. Nikari directly serves both B2B and B2C customers, though its sales focus is in the B2B segment.

The B2B segment the customers are

- architecture companies and architects
- real estate developers and EPCM consults and
- the actual corporate customer.

There has been a change in the industry as architects used to decide on the furniture too. However, now the EPCM consults are in control of costs and often they make the decision from options provided by the architect. In some cases the final corporate customers want to make the decision themselves, though this is still relatively rare.

The B2C customer groups are

- direct customers, who personally purchase their furniture directly from Nikari
- indirect customers, i.e. users of the furniture in the public spaces

Direct sales to private customers have been traditionally just a small part of Nikari's revenue. However, opportunity to use online sales channel makes it possible to serve much wider target group than earlier. Nikari furniture is enjoyed by masses of indirect private customers, who use the furniture in public spaces like schools, offices, churches and restaurants. Though they most often do not know or even care about the brand, they are brand marketing opportunity for the company.

The table below shows the assessment of the current situation at Nikari in terms of its complying with the 6 key factors for the implementation success.

Table F.5 - Innovation Effectiveness Assessment at Nikari

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
Organizational policies and practices	1. The quality and quantity of an organization's efforts to train organization's members to use new technology	2	Based on its values. Nikari relies on traditional manufacturing technology and is not very active in introducing new technologies within the company. This is a deliberate decision and the low score reflects merely to the level of technological activity than lack of training. When something new is introduced, the training is very thorough.
	2. User support – the provision of technical assistance to technology users	4	Benefit of being a small company, the user support is available for all members of the organization without any delays.
	3. Rewards, such as promotions, praise from supervisors	4	In this question, the weight is in the praise instead of a financial compensation. Ability to plan, build and commercialize a result of a creative process is extremely important.
	4. Effective communication regarding the reasons for the implementation of the new technology	4	Once again, the company is very small and the whole team is easily available. Moreover, changes in the tools and introduction of new technologies and methods are discussed with all employees.
	5. The provision of time for users to experiment with the new technology	2	As a creative company, Nikari is open for new ideas and processes as well as new technologies if they support the company goals and are aligned with the company values. However, time for technological experiments is limited as the size of the workforce is really small, One person doing experiments equals 10 % of the organization. This is important to understand in the EFF project, because small companies have to get services that are easy to integrate to their

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
			daily routines.
Implementation climate	1. Employee's shared perceptions of the importance of innovation implementation within the organization	5	The organization is fully aligned with the goals and values of Nikari. There is no question whether implementation of innovation is important or not. Creativity and innovation is in the core of Nikari.
Management Support	1. Does management support and promote innovation activities?	5	The management are also the owners. They are fully committed to innovation and they participate in the creativity meetings.
Financial Resource Availability / Accessibility	1. Does the company have financial resources available for innovation projects?	2	Compared to bigger companies the absolute financial resources are naturally limited. However, Nikari's future as a financially sustainable company is tightly linked to design innovation. In that sense, they invest proportionally very big share of the financial resources to the innovation process.
	2. Does the company know about the existence of regional, national, European or international initiatives to promote and fund innovation activities?	1	Very limited understanding of the opportunities.
Learning Orientation	1. Do the teams perceive the risk of innovation projects?	3	The team evaluates all design innovation ideas also through its commercial potential. This means that the commercial risk is always taken in to account. The process is optimized for project sales, i.e. no large-scale manufacturing without a customer order, which means that the risk is always very limited.
	2. Learning attitude?	5	The team consists mainly from creative professionals, whose ambition is to continuously improve their performance.

Key Factors	Questions for the assessment	Score (1 to 5)	Comments
Managerial Patience	1. Are managers committed to the long-term results of the innovation and understand a short-term decline of the productivity during its implementation?	5	The founders and workers of the company are natural born innovators
	TOTAL:	23,7	

The following diagram reflects the assessment performed above:

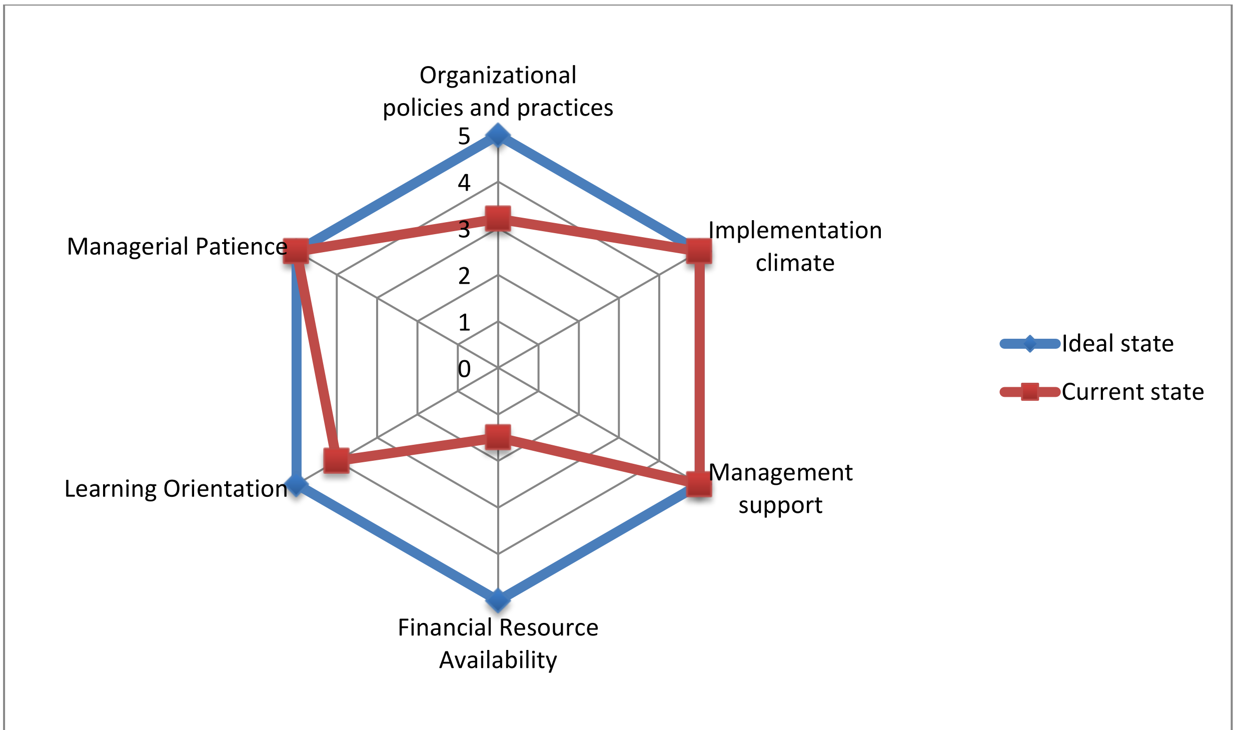


Figure F.5 - Current vs. the Targeted Situation at Nikari Oy

Nikari's management states that the long-term success of their company is based on "design innovation" and this reflects to the overall atmosphere within the company. This is clearly visible in the assessment too – Learning orientation, Managerial patience, Managerial support and Implementation climate receive high score. Nikari is eager to grow both in domestic and international markets. Global sales of furniture require international manufacturing and logistics solutions. Therefore, the company will need new technology-enhanced processes in marketing, manufacturing and logistics.